Mapping levees for river basin management using LiDAR data and multispectral aerial orthoimages

Dissertation

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Abstract

Mapping levees is important to assessing levee stability, identifying flood risks for the areas protected by levee systems, etc. Historically, mapping levees has been carried out using ground surveying methods or only one type of remote sensing data set. This dissertation aims at mapping the levees by using airborne topographic LiDAR data and multispectral orthoimages taken in the river basins of the Nakdong River. In this dissertation, three issues with mapping levees are illustrated.

The first issue is developing new methods for mapping levee surfaces by using geometric and spectral information. Levee surfaces consist of multiple objects having different geometric and spectral patterns. This dissertation proposes multiple methods for identifying the major objects and eroded areas on the levee surfaces. Multiple geometric analysis approaches such as the slope difference analysis and the elevation and area analysis are used to identify the levee top, berm, slope plates and the eroded area having different geometric patterns. Next, the spectral analysis approach, such as clustering algorithms, is used to identify major objects having different spectral patterns on the plates identified. Finally, multiple components, including the major objects and eroded areas on the levee surfaces, are identified.
The second issue is developing new methods for mapping levee lines by using the geometric and spectral information. In general, the levee lines are determined on levee surfaces by considering the geometric pattern, the types of major objects, etc. This dissertation proposes multiple methods for mapping the levee lines located on various levee surfaces. First, the three baselines (the edges extracted from the images, the cluster boundaries extracted from the identified clusters and the plate boundaries extracted from the LiDAR data) are extracted separately from different sources. Next, the judgment test is performed in order to select one baseline as the levee line segment most suitable for the levee surface. Finally, levee lines consisting of multiple baselines are generated in all levee surfaces having different geometric and spectral patterns.

The third issue is establishing a levee information system to assess failure risks for the levee systems in the Nakdong River basins. This dissertation proposes new methods for establishing these levee information systems by using the generated levee lines and identified objects on the levee surfaces. First, various levee failure risks are evaluated separately on each levee segment. Next, the level of failure risks on each levee segment is measured by using the risks for each. Finally, the levee segments having failure risks are identified along the levee lines using specific colors (red, blue, yellow and green). Using the above procedure, levee information systems are established to assess the failure risks of the levee systems in the Nakdong River basins. The established levee information systems show that the areas of Changnyeong City protected by the levees having the safe conditions from levee failure are the safest zones from flooding.
Dedication

Dedicated to my family
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CHAPTER 1: INTRODUCTION

1.1 Background

A levee is defined as "a man-made structure; usually an earthen embankment, designed and constructed in accordance with sound engineering practices to contain, control or divert the flow of water to provide protection from temporary flooding." A levee system is defined as "a flood protection system which consists of a levee, or levees, floodwalls and associated structures such as closure and drainage devices, which are constructed and operated in accordance with sound engineering practice" (Federal Emergency Management Agency (FEMA), 2013). There are different types of man-made structures to preventing flooding, but levees are different from structures such as dams, floodwalls and dikes for the following reasons (FEMA, 2013; Herbich, 2000).

1) Levees are built parallel to the course of a river to protect the property and lives behind them from floods, while dams are built to not only reduce the flood risks, but to provide water for irrigation, hydroelectric power, community water supplies, etc.

2) Levees are constructed in a variety of areas and are covered by materials such as concrete, stone, asphalt, cement, grass, clay, vegetation, etc., while floodwalls are usually constructed of stone or concrete in more urban areas.
3) Levees are constructed in river basins to protect property and lives from flooding, while dikes are constructed in coastal zones as protection from flooding from the sea.

Levees and levee systems are very important to human activities in river basins because their protective walls safeguard property and lives against rising rivers during flood events. The elements that constitute a typical levee are illustrated in Figure 1.1.

![Figure 1.1 Elements of a typical levee, modified from a figure in FEMA (2013).](image)

As seen in Figure 1.1, the levee top is defined as "the flat surface at the top of a levee that is equal to or narrower than the base," and the levee toe is defined as "the edge of the levee where the base meets the natural ground" (FEMA, 2013). The levee
top line is defined as the line located between the levee’s top and slope plates (the red line in Figure 1.1), and the toe line is defined as the line between the levee slope plates and the natural ground (the green line in Figure 1.1).

Levee surfaces are generally covered by various materials such as asphalt or gravel roads on the levee top plate and concrete or natural blocks on the levee slope plates. Multiple factors, such as the objectives of the levee construction, local geological conditions, flooding risk factors and local weather conditions, affect the type of materials selected to cover a levee’s surface. In general, levees constructed in areas where there is elevated land use and properties are designed with relatively steep slopes, while levees constructed in areas where properties are located lower are designed to have flattened slopes (United States Army Corps of Engineers (USACE), 2000). Additionally, riverside slope plates of levees are generally designed to have their surfaces covered by concrete or stone blocks because their function is to protect urban areas built along a river’s course or when surfaces are evaluated to be at risk from wave actions (Lee, 2010; USACE, 2000).

USACE classifies the types of the levees according to their location and use (USACE, 2000). First, levees are classified according to the type of area they protect—urban or agricultural. Urban levees provide community protection from flooding that includes commercial, industrial and residential structures. Agricultural levees, as indicated by their name, provide protection against flooding in rural or agricultural areas. Second, levees are classified according to their specific uses. Each type is described below (USACE, 2000).

1) Mainline and tributary levees are defined as levees that lie along a
mainstream and its tributaries.

2) Ring levees are defined as levees that entirely encircle or ring an area subject to inundation from all directions.

3) Setback levees are defined as levees built landward of existing levees.

4) Spur levees are defined as levees that project from the main levees and serve to protect the main levees from erosive action of stream currents.

5) Sub levees are located behind main levees and used as relief wells or berms during emergencies.

Figure 1.2 shows the levees according to use, as described above.

Figure 1.2 Levees according to their uses (modified from USACE (2000)).

Levees can fail for many reasons, such as overtopping, surface erosion,
internal erosion (piping), slope sliding, etc. (USACE, 2000). Earthen levees are designed, constructed and maintained by local, state or federal laws. In the United States (U.S.), USACE provides a manual that presents the basic principles used in the design and construction of levees and levee systems (USACE, 2000). In South Korea, the Ministry of Land, Infrastructure and Transport (MOLIT) provides a manual to present the basic principles for the design and construction of levees and levee systems in South Korea (MOLIT, 2009).

In the U.S., FEMA generates FIRMs, the official maps showing the hazardous areas and risk premium zones for flooding (FEMA, 2013). FIRMs are generated based on many features, including the floodway and other floodplain management information such as cross section lines. In the FIRMs, the area is protected from flooding because of the presence of a levee, concrete dike, floodwall, seawall or other structure is indicated, and the following notice is posted (FEMA, 2013):

"THIS AREA PROTECTED FROM THE 100-YEAR FLOOD FROM (Flooding Source Name) BY LEVEE, DIKE, OR OTHER STRUCTURE SUBJECT TO FAILURE OR OVERTOPPING DURING LARGER FLOODS."

Figure 1.3 demonstrates an example of the FIRMs showing the areas protected by a levee system.
USACE provides the levee safety program to assess the 2,500 nationwide levee systems in the U.S. (USACE, 2013). In the levee safety program, the inspectors conduct levee inspections using the geographic information systems (GIS) or global positioning systems (GPS) inspection tool (Figure 1.4).

Using the information from the 2,500 nationwide levee systems obtained by
the inspectors, USACE provides the national levee database (http://www.usace.army.mil/Missions/CivilWorks/LeveeSa/LeveeSafetyProgram/NationalLeveeDatabase.aspx) to let people access the information about the levee system, such as the length of the system, the number of levees that compose system, the recent levee system inspection rating and date, the levee system's location, etc. Figure 1.5 shows the national levee database provided by USACE.

Figure 1.5 National levee database provided by USACE. (Captured from the website of the National Levee Database on September 1, 2013.).

In South Korea, the WAter Management Information System (WAMIS) website provides information about systems in South Korea such as the length of the systems, the major materials covering the levee surfaces, the locations of the systems, the average slope degrees of the systems, the expected maximum water elevations of the levees, etc. Figure 1.6 shows the South Korean levee database provided by the WAMIS website (http://www.wamis.go.kr/WKF/wkf_banksaa_lst.aspx).
The ground surveying method has been used by the federal government or agencies to generate flood risk maps and manage levee systems in the U.S. and South Korea (FEMA, 2011; MOLIT, 2009; USACE, 2013). Mapping the levees is important for assessing flood risks of the areas they protect, assessing levee stability, etc. However, due to the significant length of levee systems and frequent topographic changes occurring on levee surfaces, ground surveying methods are inefficient for levee mapping tasks. Remote sensing data sets, such as airborne topographic Light Detection and Ranging (LiDAR) and multispectral images are efficient ways to conduct levee mapping tasks for the following reasons. First, LiDAR technology provides geometric information; hence, it is especially efficient for surveying wide and dynamic coastal areas and identifying coastal features that have different geometric patterns. Second, the multispectral images provide spectral information;
hence, they are especially efficient for identifying coastal features that have different spectral patterns.

Using the given LiDAR data and the multispectral aerial orthoimages, this dissertation proposes multiple advanced methods for mapping levees. First, this dissertation proposes a method for mapping the major objects covering the levee surfaces, such as asphalt, gravel roads, concrete blocks, natural blocks, levee berms and grass blocks, as well as eroded areas on levee surfaces. Second, this dissertation proposes a method for mapping levee lines located on various levee surfaces. Finally, the levee information systems assessing the failure risks for the levee systems in the study area are established by using the results of multiple objects identified on levee surfaces and the levee lines generated.

1.2 Literature Review

Historically, research on levee mapping and levee stability assessment has been carried out using ground surveying methods, remote sensing data sets or flood modeling.

Research on mapping levee or dike lines has been carried out by using LiDAR technology. Brügelmann (2000) developed a method for extraction the dike lines from airborne topographic LiDAR data using grayscale images, which represent the range of the height component (Z coordinate) of LiDAR data. Brzank et al. (2005 and 2008) extracted the structure lines, including the dike lines in coastal areas, from the airborne topographic LiDAR data using the tangent function.

Research on mapping levee surfaces has been carried out by using the

Research on mapping levee surfaces by using LiDAR technology or other methods also has been carried out. Evans et al. (1998) used the seismic method to detect dikes. Bishop et al. (2003) integrated LiDAR data, electromagnetic data sets and geologic data for identifying river basins, including levee systems. Bishop et al. (2004) extracted the levee crown from laser radar data using the least-cost path method and the flip 7 filter. Flos (2011) used the historical LiDAR data sets to identify topographic changes occurring on dike surfaces. Mahrooghy et al. (2012) detected levee slides from the terrasar-x data. Cundill et al. (2013) inspected the soil moisture and grass quality on the levee surfaces by using multispectral, hyperspectral and thermal images.

Research on assessing levee stability using remote sensing data sets or ground surveying data has been carried out. Collins et al. (2009) used terrestrial LiDAR data sets to analyze levee failures caused by Hurricane Katrina. Dunbar (2011) used LiDAR data for the levee assessment using geophysical methods. Casas et al. (2012) evaluated levee stability by one-dimensional analysis with geometric parameters such as heights and slopes derived from the LiDAR data.
Research on the importance of levee systems to preventing natural disasters such as flooding has been carried out. The American Society of Civil Engineers (ASCE) (2010) shows that flood prevention structures such as levee systems cannot reduce the risk of flooding to zero. The National Research Council (NRC) (1982) shows that one-third of the flood disasters that have occurred in the U.S. are related to levee failures. McClain (2000) shows that levee maintenance is effective in enhancing levee stability during rainfall events.

Since the topographic changes occurring on levee surfaces, such as levee failures, are closely related to the river flow patterns, research on failures occurring on levee surfaces has been carried out by using flood modeling. Van et al. (2008) implemented the analysis of levee failures in horizontal translation caused by water-filled gaps. Di Baldassarre et al. (2009) implemented the change analysis of the length of the levee system on flood propagation. Flor et al. (2010) evaluated levee failure susceptibility using logistic regression analysis. Zinke et al. (2011) used three-dimensional numerical modeling to compute levee depositions. Dierauer et al. (2012) evaluated levee setbacks using one-dimensional hydraulic modeling and flood-loss modeling.

Research on mapping other coastal features, such as shorelines, blufflines, and vegetation in the river basins, has been carried out to manage coastal resources, protect coastal environments and develop coastal zones. Briese (2004) proposed a method for extracting coastal features from the airborne topographic LiDAR data using three-dimensional breakline models. Li et al. (2008) and Liu et al. (2009) developed a slope-based method for bluffline extraction using LiDAR data and aerial

The limitations of mapping levees that was performed by the historical research and challengeable topics on levee mapping performed in this dissertation are illustrated in the following paragraphs.

1) The levee surfaces consist of multiple components that have different geometric and spectral patterns. However, the historical research carried out to identify multiple components on the levee surface considers only one pattern type. This dissertation uses two types of data sets and employs multiple analysis methods to identify various components on levee surfaces. Hence, identification of the levee components using the geometric and spectral information derived from multiple remote sensing data sets is the challengeable topic in this dissertation.

2) Levee lines are located on levee surfaces that have various spectral and
geometric patterns. The historical research on mapping dike or levee lines was carried out using only the geometric parameters derived from LiDAR data. Hence, the levee lines generated by the historical research are limited in their ability to describe various levee surfaces. Therefore, identifying the levee lines on various levee surfaces is the challengeable topic in this dissertation.

3) Establishing the levee information system is important to assessing the failure risks of the levee systems in the study area. The historical research on assessment of levee stabilities was carried out by using only LiDAR data or ground surveying method. However, using only LiDAR data limited the research to identifying the various types of failure risks occurring on the levee surfaces and assessing the failure risks of the levees that consist of various materials. Additionally, the study area (the Nakdong River basins) selected in this dissertation suffers serious damage from annual floods. Hence, establishing the levee information system to assess the failure risks of levee systems in the study area is also a challengeable topic in this dissertation.

1.3 Issues and significance of this dissertation

Levee mapping is critical for the evaluation of levee stability, determination of levee maintenance and analysis of the flooding risks of the areas behind the levees. There are several important issues in levee mapping tasks that would be resolved in this dissertation.

1) Mapping levee surfaces: The levee surfaces consist of various components such as the top, slope and berm plates having different geometric patterns, and
multiple objects such as asphalt, gravel or soil roads, and concrete, grass or natural blocks located on the top, slope or berm plates having different spectral patterns. In addition, the eroded areas are also randomly located on levee surfaces. In this dissertation, we propose multiple methods for identifying multiple major objects as well as the eroded areas having different geometric and spectral patterns.

2) Mapping levee lines: The levee lines are located on various levee surfaces having different geometric and spectral patterns. The three baselines, such as the edges extracted from the image sources, the cluster boundaries extracted from the identified cluster and the plate boundaries extracted from the LiDAR data, are separately generated, and one baseline is selected as the levee line segment on the levee surface by the judgment test. This dissertation proposes a new method for generating levee lines that consist of multiple baselines that are suitable to describe various levee surfaces.

3) Mapping levee information systems: Levee information systems are necessary for estimating the failure risks of levee systems and generating flood risk maps. This dissertation suggests a method for mapping levee information systems assessing the failure risks of the levee systems located in the Nakdong River basins.

1.4 Types of levees

In general, the types of materials that cover the slope plates of flood prevention structures affect the erosion rates and the risk types occurring on their
surfaces (USACE, 2000; Herbich, 2000). To identify the major objects on the levee surfaces efficiently and to predict various types of levee failure risks that can occur on levee surfaces, we divide the levees into the two types: concrete levees (CLs) and green levees (GLs). The CL consists of paved surfaces on top and riverside slope plates. The typical CL has slope protection layers on its riverside slope plate, and these slope protection layers are generally made with concrete blocks. The typical CL also has a paved road, such as the asphalt roads on its top plate, and artificial grass blocks on its landside slope plate. Figure 1.7 shows the cross section of the typical CL showing its major objects, and Figure 1.8 shows examples of typical CLs and their major objects in high-resolution multispectral images.

![Cross section of the typical CL showing its major objects.](image-url)

Figure 1.7 Cross section of the typical CL showing its major objects.
Example 1 of CLs  

Example 2 of CLs  

Figure 1.8 Examples of typical CLs in high resolution multispectral images.

In general, the GL consists of unpaved surfaces such as the gravel, soil or vegetation roads on its top plate and natural blocks on its side slope plates. Figure 1.9 shows the cross section of a typical GL showing its major objects, and Figure 1.10 shows examples of the typical GLs and their major components in high-resolution multispectral image sources.

Figure 1.9 Cross section of the typical GL showing its major objects.
In this dissertation, the levees that consist of paved surfaces only on their top or slope plate are called the partial CLs.

Levee line locations are generally determined by considering the surroundings, the geometric patterns and the major objects on levee surfaces. Historically, levee lines are designed to be located on the levee surfaces where the geometric patterns change (MOLIT, 2009). To protect levee surfaces, the levee lines are located on the areas where the geometric patterns and major objects on the levee surfaces are preserved (Kim et al., 2004; Lee, 2010).

The levee berm is defined as a man-made mound located between the levee toe and top, and generally has been used as trail roads for human activities and vehicles. The width and height of the levee berm is primarily dependent on ground conditions, levee heights and the amount of available land (USACE, 2000). Historically, the levee berm was constructed on the levee systems in South Korea;
however, that has not been defined since 2003 for the following reasons (Yoon, 2005; MOLIT, 2009).

Reason 1: The levee berm causes the risk of levee failure to increase because water can remain on the levee berm during rainfall events.

Reason 2: The levee berm can be easily damaged when sliding occurs on levee surfaces.

Figure 1.11 shows a cross section of a typical levee in South Korea. Figure 1.11 (a) shows a cross section of a typical levee in South Korea before 2003, and Figure 1.11 (b) shows a cross section of a typical levee in South Korea after 2003.

(a) Cross section of a typical levee in South Korea before 2003.

Figure 1.11 Cross section of a typical levee in South Korea (Continued).
Figure 1.11 Continued

(b) Cross section of a typical levee in South Korea since 2003.

1.5. Overview of the Dissertation

This dissertation proposes an approach for mapping levee systems for river basin management using airborne topographic LiDAR data and multispectral aerial orthoimages. Chapter 1 introduces the levee and levee systems, reviews the historical research on mapping levees, illustrates the limitations of previous research on mapping levees and illustrates challengeable topics that will be performed in this dissertation. Chapter 2 introduces multiple methods for mapping the major components that cover levee surfaces. The levee top and slope plates are generated from the slope maps by the slope difference analysis and the levee top plates are refined by morphological filtering. Then the breakline detection method is employed to separate the slope plates and neighboring objects. The levee berms and levee failure areas are identified by the elevation and area analysis. Finally, clustering algorithms
are employed to identify the major objects of the top, slope and berm plates. Chapter 3 introduces new methods for mapping levee lines. The plate boundaries are extracted from LiDAR data by using the spline function; the edges are extracted from the images by using the edge detection method; and the cluster boundaries are extracted from the identified clusters by using the modified convex hull algorithm. The plate boundaries are generated in all levee systems, and the edges and the cluster boundaries are partly generated based on the major objects on the levee surfaces. One baseline is selected from the different baselines, using the judgment test, as the levee line segment. Chapter 4 introduces a method for establishing the levee information system assessing the failure risks of levee systems in the study area by using the results obtained in Chapters 2 and 3. Chapter 5 shows the datasets and study area, discusses the general characteristics of the generated levee lines, analyzes the accuracies of the generated levee lines using the various factors and assesses the failure risks of the levee systems in the study area. Chapter 6 summarizes all achievements obtained in this dissertation and suggests the direction for future research.
CHAPTER 2: MAPPING LEVEE SURFACES

2.1 Background

This chapter discusses mapping levee surfaces using the geometric information obtained from the LiDAR technology and the spectral information obtained from multispectral aerial orthoimages. Multiple components located on the levee have different spectral and geometric patterns that can be identified by using multiple analysis methods. Figure 2.1 shows the procedure for mapping these surfaces. The procedure includes multiple steps such as slope difference analysis, elevation and area analysis, median filtering, morphological filtering, clustering algorithms and the breakline detection method for mapping levee surfaces.
Figure 2.1 Diagram showing the procedure for mapping levee surfaces.

In the diagram shown in Figure 2.1, the LiDAR Digital Surface Model (DSM) is generated by using the linear interpolation method. Then the slope map is generated by calculating the maximum rate of change between each pixel and its neighbors. The flat and steep plates are generated separately from the slope map using slope difference analysis. The levee locations are identified by selecting the slope plates pairs from the steep plates. The breakline detection method is applied to distinguish the levee slope plates and other objects. The elevation and area analysis is carried out to separate the levee top plate, the levee berm and the eroded plates. Morphological filtering is applied to refine the levee top plate. Using this procedure, the levee top,
slope, berm and eroded plates with different geometric patterns are identified. Multiple clustering algorithms are applied to identify the various objects (asphalt road, gravel road, concrete blocks, soil, vegetation, etc.) on the levee top, slope and berm plates. Major objects on levee surfaces, such as asphalt, gravel, soil roads and vegetation on the levee top plates, and concrete, grass, soil and vegetation on the levee slope and berm plates are identified by using the clustering algorithms. Finally, levee components such as major objects and the eroded areas on levee surfaces having different spectral and geometric patterns are identified. The accuracy of results show that major objects on the levee surfaces are well identified using the above procedure.

2.2 Generating the slope map

The LiDAR data consists of the irregularly distributed points. To represent the topographic surfaces using the grid format that consists of the constant cells, the DSM is generated from the given LiDAR point cloud (the point density of the given LiDAR data: 1.5 points / m²). The interpolation method is employed to estimate the elevation of each cell in the LiDAR DSM generated. There are the many interpolation methods, such as the Inverse Distance Weighted (IDW), the linear interpolation, the kriging interpolation, the natural neighbor interpolation, the spline interpolation, etc. In general, slopes are significantly changed at the levee top and toe surfaces. Hence, to detect the levee top and slope plates, the linear interpolation method is used to generate the LiDAR DSM since it has characteristics that describe the features, sharp edges and steep surfaces (ArcGIS 9.2 Desktop Help, 2013). The point density of the LiDAR data plays an important role in determining the grid resolution of the LiDAR
DSM created. There is no reference by which to calculate the grid resolution of the DSM as a function of the point density of LiDAR data. In this research, the resolution of 1m is set as the grid resolution of the DSM to make sure each cell of the DSM includes at least one LiDAR point. Figure 2.2 shows one section of the LiDAR DSM generated from LiDAR points using the linear interpolation method. In Figure 2.2, the objects with brightly colored pixels have a relatively higher elevation than neighboring pixels.

![Figure 2.2 One section of the LiDAR DSM generated by the LiDAR points using the linear interpolation method.](image)

In general, the LiDAR DSM often includes outliers, which are the pixels that are significantly different in elevation compared with all nearby pixels. These outliers are caused by random errors or objects such as utility poles, and these outliers, located
near levees, can cause difficulty when trying to detect levee mounds, which generally have gradual slopes. To remove these nearby outliers and preserve the mounds that make up the levee’s top and slope plates, filtering is employed. Research on minimizing these outliers by filtering to extract coastal features has been carried out by Liu et al. (2009) and Choung et al. (2013). In this research, a median filter is employed, which is a non-linear filter based on neighborhood ranking (Schenk, 1999; Wolf and Dewitt, 2000). The major advantages of median filtering over other linear filters are eliminating points with much larger values than immediate neighboring points and avoiding data modification (Schenk, 1999; Liu et al., 2009). Figure 2.3 shows refinement of the LiDAR DSM using the median filter: (a) One section of the original LiDAR DSM that includes the outlier (the feature in the red circles); and (b) one section of the refined LiDAR DSM that does not have the outlier after the median filtering.

(a) One section of the original LiDAR DSM that includes the outlier (the feature in the red circles).

Figure 2.3 Refinement of the LiDAR DSM using the median filter (Continued).
In Figure 2.3, the outliers located near the levees in the raw LiDAR DSM (Figure 2.3(a)) are removed and the mounds that consist of the levee's top and slope plates are preserved in the refined LiDAR DSM (Figure 2.3(b)). The next step is to generate the slope map from the refined LiDAR DSM by calculating the maximum rates of elevation difference between each pixel of the refined LiDAR DSM and its neighboring pixels (ArcGIS 9.2 Desktop Help, 2013). In the generated slope map, an intensity value for each pixel represents the slope degree of the area. In general, the pixels having low slope values represent the objects that have relatively flat terrains, and the pixels having high slope values represent the objects that have relatively steep terrains. Figure 2.4 shows one section of the generated slope map.
2.3 Generating the levee plates

Typical levees consist of steep plates with elevations that gradually increase from the toe to the top on their surfaces, and flat plates with stable surface elevations. Steep and flat plates are generated separate from the slope map using the slope difference analysis. Historically, levees constructed in South Korea are designed to have slope degrees from 18.43° (1V (Vertical):3H (Horizontal)) to 33.69° (1V:1.5H) on their slope plates (Lee, 2010; MOLIT, 2009; Yoon, 2005). Considering geometric changes, such as erosion occurring on the levee slope plates, +/- 10° is added to the slope degree range for selecting the pixels representing the levee slope plates. Hence, the slope degree range to generate steep plates, including the levee slope plates, is set as [8.43°, 43.69°]. The slope degree range for the extraction of flat plates, including the levee top plates, is set to avoid the first range and uses the lower degree values. Hence, it is set as [0°, 8.43°]. Using the above two ranges, the two types of plates are
generated separate from the slope map. In this dissertation, the binary image generated using the first slope degree range is called the steep plate image, and the binary image generated using the second slope degree range is called the flat plate image. In general, the steep plate image shows the objects that have steep terrains, such as the levee slope plates, the building walls, etc., while the flat plate image shows the objects that have flat terrains, such as the natural ground, the levee top plates, highways, roofs, etc. Flat and steep plate images generated separate from the slope map, using slope difference analysis, are shown in Figure 2.5. Figure 2.5 (a) shows one section of the steep plate image (the right column) and the flat plate image (the left column). Figure 2.5(b) shows multiple levee components shown in the multispectral orthoimages.

<table>
<thead>
<tr>
<th>The flat plate image</th>
<th>The steep plate image</th>
</tr>
</thead>
</table>

(a) The flat plate and steep plate images

Figure 2.5 Flat and steep plate images generated separately from the slope map using slope difference analysis (Continued).
In Figure 2.5, the levee top plates and the ground are identified in the flat plate images, and the levee slope plates are identified in the steep plate images. Figure 2.6 shows the flat plates (pink polygons) selected from the flat plate image, and the steep plates (yellow polygons) selected from the steep plate image.

Figure 2.6 Flat plates (pink polygons) and the steep plates (yellow polygons).

The levees have different geometric characteristics from objects such as
highways or bridges because the levee mounds consist of slope plates on both sides and are located along a river's course. Hence, the steep plates that represent the levee slope plate pair are selected from the steep plate image to identify the levee locations in the study areas. Figure 2.7 shows an example of the selected levee slope plates pairs (yellow polygons).

![Figure 2.7 Example of the levee slope plates pairs (yellow polygons).](image)

In Figure 2.7, some areas of the levee slope plates (yellow polygons) are not separated from neighboring objects (houses, trees, buildings, etc.) located near the levees. Additionally, levee toes generally have sharp edges since their surfaces are usually cut by water flow (USACE, 2006), and the levees are designed to have certain degrees on their slope plates. Hence, for detecting the levee boundaries generally located at the sharp edges of the toe surfaces and distinguishing between the levee slope plates and neighboring objects, the breakline detection method is employed. In
this research, the breakline detection method developed by Choung et al. (2013) is employed for mapping of the levee boundaries. The method is the semi-automatic method for constructing a 3-D breakline from the LiDAR data by connecting manually selected line segments. This method is efficient for detecting line segments that are located at the sharp edges (step or ramp edges) of coastal features such as bluffs (Choung et al., 2013). This method includes the following multiple steps. First, median filtering is applied to the LiDAR points to remove the outliers, which are significantly different in elevation compared with neighboring points. Second, the Delaunay triangulation networks are constructed using the LiDAR points located in the levee slope plates. The next step is to find an edge that serves as levee toe line candidate by examining the orientation of the two surface triangles that intersect at this edge. Using the above procedure, Method 1 and Method 2 are employed to extract the levee toe edges from the vectors. The equation used in Method 1 and Method 2 is (Choung et al., 2013):

\[
A(e) = \arccos\left(\frac{n_i}{\|n_i\|} \cdot \frac{n_j}{\|n_j\|}\right)
\]  

(2-1)

In Method 1, \(e\) is the edge of the Delaunay triangulation network, \(A(e)\) is the value of a dihedral angle defined by the two normal vectors of the two adjacent triangles, and \(\|n\|\) and \(n\) correspond to the norms of these two normal vectors. In Method 2, \(n_i\) and \(n_j\) are defined as the average normal vectors of the vertices \(x_i\) and \(x_j\) opposite to the edge \(e\). These average normal vectors are computed using all the normal vectors of the triangles sharing vertices \(x_i\) and \(x_j\), respectively. Using both methods, the levee toe line candidates are extracted separately, and we select a set of
candidate edges, suitable for the levee toe line segment, from a combination of edge groups A and B that are extracted by Method 1 and Method 2, respectively. The next step is to remove the unsuitable edges by examining the elevation difference between the two endpoints of the edge and the edge connectivity. The final step is to manually select the line segments located in the levee slope plates that were selected from the steep plate image. Using the selected line segments, the levee boundaries are constructed by connecting the selected line segments. The levee boundary generated can separate the levee slope plates from neighboring objects. Figure 2.8 shows the levee slope plates (brown polygons) separated from the other objects (yellow polygons) by the levee boundaries (red lines) that are generated by the breakline detection method.

Figure 2.8 Levee slope plates (brown polygons) separated from the other objects (yellow polygons) by the levee boundaries (red lines) that are generated by the breakline detection method.
The next step is to distinguish the levee top plates from the multiple flat plates extracted from the flat plate images. After the levee boundaries are generated using the breakline detection method, multiple flat plates, located between the levee boundaries, are selected. Figure 2.9 shows the multiple flat plates (pink polygons) on the levee surfaces.

![Figure 2.9 Multiple flat plates (pink polygons) on the levee surfaces.](image)

Among the multiple flat plates shown in Figure 2.8, the plate that has the highest average elevation is selected as the initial levee top plate. The plates with a lower average elevation than the selected plate are defined as the other flat plates. Figure 2.10 shows the selected levee top plate (pink polygon).
Figure 2.10 Initial levee top plate (pink polygon).

Due to failures generally occurring on the top surfaces, the selected levee top plate often has small holes, gaps or narrow breaks on its surfaces (red circles in Figure 2.10). To remove these narrow breaks, small holes or gaps on the levee’s top plate, morphological filtering is applied to the initial levee top plate in the binary image. Morphological filtering is a technique for the analysis and processing of geometrical structure of the image object by creating a newly shaped object by running a specific-shaped Structure Element (SE) over the input object (IO). Compared to other nonlinear filtering, morphological filtering has several advantages explained as follows. First, morphological filters can be simply implemented and have less computation. Second, morphological filtering has geometric filtering property, which can preserve geometric features of the input objects and filter the noises in the input objects out by controlling filter design. Due to these characteristics, the morphological filtering is employed to refine the levee top plate, generally have the linear structures. The basic operations for morphological filtering are erosion and dilation: erosion is
used to shrink the IO A by using the SE B, and dilation is used to expand the IO A by using the SE B. In the binary image, the morphological erosion of the IO A by the SE B is defined as (Gonzalez and Woods, 2008):

\[ A \ominus B = \{z(B)_z \cap A^c = 0\} \quad (2-2) \]

where \((B)_z\) is the translation of a set \(B\) by point \(z\) \((z_1, z_2)\). In the binary image, morphological dilation of the IO A by the SE B is defined as (Gonzalez and Woods, 2008):

\[ A \oplus B = \{z(B)_z \cap A \neq 0\} \quad (2-3) \]

where \(B\) is the reflection of a set \(B\), and \(B^c\) is the reflection of a set \(B\) about its origin, and shifted by point \(z\) \((z_1, z_2)\). The morphological erosion and dilation procedures are operated by matching the boundary pixels in the IO and the center point of the SE (Gonzalez and Woods, 2008). The pixel value of the output object is the minimum value of all the pixels in the input pixel's neighborhood by using the morphological erosion operator in the binary image. The pixel value of the output object is the maximum value of all the pixels in the input pixel's neighborhood by using the morphological dilation operator in the binary image (Gonzalez and Woods, 2008). Hence, IO is eroded or dilated by SE in all directions by using the morphological erosion or dilation procedure. The morphological closing of the IO A by the SE B is defined as (Gonzalez and Woods, 2008):

\[ A \bullet B = (A \oplus B) \ominus B \quad (2-4) \]

which says that the morphological closing of IO A by SE B is the dilation of IO A by SE B, followed by the erosion of the result by SE B. Figure 2.10 shows the operations
of the morphological closing operator. In Figure 2.11, the small holes and the narrow breaks of the IO are filled by the morphological closing operator.

Figure 2.11 Operations of the morphological closing operator (Modified from Gonzalez and Woods, 2008).

In this research, the morphological closing operator is used to fill the small holes and gaps on the selected levee top plates shown in Figure 2.10. Since the levee top plates have a linear structure with stable widths, the shape of the SE is set as squares. To preserve the original width of the IO and fill the small holes or gaps in the IO, the width of the SE should be similar to the width of the levee top plate. According to the construction law from MOLIT of South Korea, the minimum width
of the top plates of levees in South Korea is set as the 4 m (MOLIT, 2009). Hence, the width of the SE is also set as 4 m. Figure 2.12 shows the refined levee top plate (pink polygon) by using the morphological closing operator.

Figure 2.12 Refined levee top plate (pink polygon) by using the morphological closing operator.

Compared with the initial levee top plate shown in Figure 2.10, the width of the refined levee top plate is preserved. The holes or the gaps in the initial levee top plate in Figure 2.10 are removed in the refined levee top plate shown in Figure 2.12. After the levee top plates are refined by morphological filtering, the levee berm plates and eroded plates are separated in the other flat plates. In Figure 1.13, the levee berm is a flat mound on the levee surface and is 3m lower than the levee top (Yoon, 2005; MOLIT, 2009). Considering the definition of the levee berm, we separate the levee berm plates from the other flat plate group by using the elevation and area analysis described in the following paragraphs.
Assumption 1: The plate, with an elevation in the range determined by the

elevation analysis, is defined as the levee berm candidate plates and the range

is determined using the following equation.

\[ LT - T - 1 \text{ m} \leq LBC \leq LT - T + 1 \text{ m} \]  (2-5)

where the LBC denotes the average elevation of the levee berm candidate

plates, the LT denotes the average elevation of the levee top plate and the T

denotes the threshold of the elevation difference between the levee top and the

levee berm. Due to the possible topographic changes occurring on the levee

surfaces, +/- 1 m is added into the range to select the levee berm candidate

plates. Following the definition of the levee berm shown in Figure 1.1, the T

is set as 3m and the flat plate, with an elevation in the above range, is

identified as the levee berm candidate plate.

Assumption 2: There is no reference to the size and length of the levee berm.

We assume that the levee berm plates have the appropriate area since they are

generally used as roads (MOLIT, 2009). Hence, we select the levee berm

plates from the candidate plates by using the following equation.

\[ AB \geq TA \]  (2-6)

where AB denotes the areas of the candidate plates and TA denotes the

threshold of the area. Based on an empirical analysis, the plate with an area

larger than 100 m\(^2\) is selected as the levee berm plate, and smaller than 100 m\(^2\)

is defined as the eroded plate. Hence, the TA is set as 100.

Using the elevation and area analysis described in the above paragraphs, the

plate that satisfies the above two assumptions is selected as the levee berm plate;
otherwise, it is defined as the eroded plate. Figure 2.13 shows the levee top plate (pink), the levee slope plates (brown) and the eroded plates (yellow) on the levee surfaces. Figure 2.14 shows the levee top plate (pink), the levee slope plates (brown) and the levee berm plate (purple) on the levee surfaces.

Figure 2.13 Levee top plate (pink), the levee slope plates (brown) and the eroded plates (yellow) on the levee surfaces.
Figure 2.14 Levee top plate (pink), the levee slope plates (brown) and the levee berm plate (purple) on the levee surfaces.

Through all procedures, the levee top, slope, berm and eroded plates that have different geometric patterns are identified (see Figures 2.13 and 2.14).

2.4 Identification of the major objects on the levee plates

Levee top and slope plates consist of multiple objects, and each type of levee (CL and GL) consists of different component combinations. Table 2.1 shows the general major objects located on the CL or GL surfaces.

Table 2.1 General major objects located on CL or GL surfaces.

<table>
<thead>
<tr>
<th>Levee type</th>
<th>Plate type</th>
<th>Major objects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete Levee</td>
<td>Levee top</td>
<td>Paved roads such as asphalt</td>
</tr>
<tr>
<td>(CL)</td>
<td>Levee slope</td>
<td>Concrete block (on the riverside slope)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Grass block (on the landside slope)</td>
</tr>
<tr>
<td>Green Levee</td>
<td>Levee top</td>
<td>Unpaved road such as gravel, soil or vegetation</td>
</tr>
<tr>
<td>(GL)</td>
<td>Levee slope</td>
<td>Natural blocks such as soil, clay, vegetation, sand, etc.</td>
</tr>
<tr>
<td></td>
<td>Levee berm</td>
<td>Gravel or soil road</td>
</tr>
</tbody>
</table>
Since these objects have different spectral characteristics that can be identified in the multispectral image sources, multispectral bands, such as red, green, blue and Near Infra-Red (NIR), are used to identify these objects. In addition, the LiDAR systems also provide the intensity value for each return, and the LiDAR intensity value is determined by an object’s reflectance. This can be used to identify the land-cover classes (Wang and Glenn, 2009). Hence, for identification of multiple components located on the levee surfaces, the spectral information obtained from the multispectral orthoimages and the LiDAR intensity values obtained from the LiDAR system are used as the main parameters. Clustering is the machine learning technique widely used to extract the thematic information from the multispectral images in remote sensing application and research (Jensen, 2004; Asmus et al., 2010; Xu et al., 2011). Clustering is an unsupervised learning technique to organize the objects into multiple groups, with members that are similar in some way without the training samples (Tuia, 2009; Halder, 2011). In this research, the two traditional clustering algorithms such as the K-means and the ISODATA algorithms are used to identify the major objects located on the top / slope / berm plates. Reasons for using the clustering algorithms are explained as follows. First, clustering does not require the training samples to classify clusters with similar members that have the different spectral characteristics. Second, each major object on the various levee surfaces has the definite spectral characteristics, then we assume that a certain sample of one object cluster could not be included in another object cluster. Based on the above reasons, this research employs the K-means and the ISODATA algorithms separating the clusters by the straight line to identify the multiple major objects on the top / slope /
berm plates.

In this research, the K-means clustering and the ISODATA clustering, widely used clustering algorithms in the remote sensing techniques (Li et al., 2010), are separately employed to extract the major objects from the CL and GL surfaces. Since K-means clustering requires the input of the number of generated clusters, K-means clustering is appropriate for classifying the objects when the users have priori knowledge of the objects (Abbas, 2008). Priori knowledge of the multiple components covering the CL surfaces is provided by the WAMIS website (http://www.wamis.go.kr/). Using the priori knowledge provided by the WAMIS website, the number of necessary clusters is generated by K-means clustering. K-means clustering is performed using the following procedure (Arthur and Vassilvitskii, 2006; MathWorld, 2013):

Step 1. The number of clusters is defined by the user.
Step 2. Each cluster is initialized by an arbitrary assignment of the samples to the cluster.
Step 3. The mean of each cluster is calculated.
Step 4. Each cluster sample is reassigned with the nearest mean.
Step 5. If the results of the reassignment are not changed, the procedure is stopped; otherwise, go back to Step 3.

ISODATA clustering is similar to K-means clustering with the advantage over K-means clustering being that ISODATA clustering allows for different numbers of clusters, while K-means assumes that the number of clusters is known a priori (Ahmad and Sufahani, 2012). Since ISODATA clustering is a self-organizing
algorithm using multiple parameters, it requires less human input than K-means clustering (Li et al., 2010). ISODATA clustering is performed using the following procedure (Memarsadeghi et al., 2007; Pughineanu and Balan, 2011; Ahmad and Sufahani, 2012; ArcGIS 10.1 Desktop Help, 2013).

Step 1. The cluster centers are randomly placed and the samples are assigned based on the shortest distance to the cluster center.

Step 2. For each cluster, the standard deviation and the distance between cluster centers are calculated.

i) The cluster is split if its standard deviation is greater than the threshold (A) of the maximum standard deviation of the clusters.

ii) The cluster is merged if the distance between them is less than the threshold (B) of the minimum distance between the cluster centers.

iii) The cluster is eliminated if the number of cluster samples is fewer than the threshold (C) of the minimum number of cluster samples, and they are reassigned to an alternative cluster.

Step 3. New cluster centers are computed, and a second iteration is performed with the new cluster centers.

Step 4. Further iterations are performed until:

i) The average distance between the clusters falls below the B.

ii) The threshold (D) of the maximum number of the iteration times is reached.

iii) During the procedure, the number of the clusters finally generated does not exceed the maximum number of generated cluster (E).
The appropriate values of each parameter are determined by multiple experiments. In this research, D is set as 100, B is set as 10, A is set as 5, C is set as 10 and E is set as 10 for classifying all objects on the GL surfaces. After the procedure is completed, several clusters are generated, and clusters that represent the same objects are manually merged per the user's determination.

The major components on the CL top and slope plates are identified by using K-means or ISODATA clustering. In this research, the major component of the CL riverside slope plate is generally concrete block used as the slope protection layer, and the major component of the CL landside slope plate is generally grass blocks. After we generate the clusters of the major components of the CL slope plates by K-means or ISODATA clustering, the final clusters are defined in the following assumptions.

Assumption 1. Grass block can contain pebbles or small stones whose spectral characteristics are similar to concrete block on the CL riverside slope plate.

Assumption 2. The samples of the grass cluster that appear on the CL riverside slope plate represent the area where concrete materials are covered by the grasses.

Following the above assumptions, the grass samples that appear on the CL riverside slope plate are defined as grasses on concrete block, and the concrete samples that appear on the CL landside slope plate belong to the grass block cluster. Figure 2.15 shows the asphalt road (red), concrete block (blue) and grass block (green) on the CL top and slope plates identified by K-means clustering.
Figure 2.15 Asphalt road (red), concrete block (blue) and grass block (green) on the CL surfaces identified by K-means clustering.

The next step is to identify the major objects on the identified levee berm plates. Since we do not have priori knowledge of the major objects located on the levee berm, ISODATA clustering is employed to identify them. Figure 2.16 shows the two clusters [(the soil road (brown) and the gravel road (cyan)] identified on the levee berm plate shown in Figure 2.14 by ISODATA clustering.

Figure 2.16 Two clusters [the soil road (brown) and the gravel road (cyan)] identified on the levee berm plate shown in Figure 2.14 by ISODATA clustering.
The results in Figures 2.15 and 2.16, Figure 2.17 show all major objects on the CL surfaces: the asphalt road (red), concrete blocks (blue) and grass blocks (green) on the top and slope plates, and the soil road (brown) and the gravel road (cyan) on the berm plates.

Figure 2.17 All major objects on the CL surfaces: asphalt road (red), concrete blocks (blue) and grass blocks (green) on the top and slope plates and the soil road (brown) and the gravel road (cyan) on the berm plates.

The major objects on the GL top and slope plates shown in Figure 2.13 are also separately identified by using K-means or ISODATA clustering. Figure 2.18 shows all major objects on the GL surfaces: the gravel road (cyan), soil (orange) and vegetation (moss green) identified by ISODATA clustering and the eroded plates (yellow).
2.5 Accuracy of the identified objects by clustering algorithms

Accuracy of the identified objects by both clustering algorithms is measured by using the 140 checkpoints determined by the experienced expert. Figure 2.19 shows an example of the checkpoints (red dots) located on the levee surface.
Figure 2.19 Example of the checkpoints (red dots) located on the levee surface.

Table 2.2 shows the accuracy of the identified objects generated by both clustering algorithms on the CL surfaces, and Table 2.3 shows the accuracy of the identified objects generated by both clustering algorithms on the GL and levee berm surfaces.
Table 2.2 Accuracy of the identified objects generated by both clustering algorithms on the CL surfaces.

<table>
<thead>
<tr>
<th></th>
<th>K-Means</th>
<th>ISODATA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overall accuracy</td>
<td>Overall accuracy</td>
</tr>
<tr>
<td></td>
<td>Producer's accuracy</td>
<td>User's accuracy</td>
</tr>
<tr>
<td>Asphalt Road</td>
<td>90%</td>
<td>88%</td>
</tr>
<tr>
<td>Concrete blocks</td>
<td>92%</td>
<td>92%</td>
</tr>
<tr>
<td>Grass blocks</td>
<td>83%</td>
<td>77%</td>
</tr>
</tbody>
</table>

Table 2.3 Accuracy of the identified objects generated by both clustering algorithms on the GL and levee berm surfaces.

<table>
<thead>
<tr>
<th></th>
<th>K-Means</th>
<th>ISODATA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overall accuracy</td>
<td>Overall accuracy</td>
</tr>
<tr>
<td></td>
<td>Producer's accuracy</td>
<td>User's accuracy</td>
</tr>
<tr>
<td>Gravel Road</td>
<td>88%</td>
<td>84%</td>
</tr>
<tr>
<td>Soil</td>
<td>60%</td>
<td>92%</td>
</tr>
<tr>
<td>Vegetation</td>
<td>83%</td>
<td>77%</td>
</tr>
</tbody>
</table>

Tables 2.2 and 2.3 show that K-means clustering has similar accuracy to the ISODATA clustering for identifying the major objects on the CL surfaces, and the ISODATA clustering has higher accuracy than K-means clustering for identifying the major objects on the GL surfaces. In general, the CL surfaces consist of artificially constructed objects that are visually well-distinguished and rarely ruined due to the paved surfaces. These characteristics also cause the objects on the CL surfaces to be well-identified by both clustering algorithms. However, the GL surfaces consist of naturally generated objects that are easily ruined. These characteristics make it
difficult to determine the number of necessary clusters made by K-means clustering. Figure 2.20 shows the classification results of the three clusters (gravel road, soil and vegetation) identified by both algorithms.

The original image showing the three major components (gravel road, soil and vegetation) located on the GL surfaces

Classification results of the three clusters (gravel road, soil, vegetation) by ISODATA clustering

Classification results of the three clusters (gravel road, soil, vegetation) by K-means clustering

Figure 2.20 Classification results of the three clusters (gravel road, soil and vegetation) identified by both algorithms.
In Figure 2.19, some segments of the gravel roads are not classified by K-means clustering due to ruins on their surfaces (red circle in the right column of Figure 2.19), while these segments are well identified as the gravel road cluster by ISODATA clustering (red circle in the left column of Figure 2.19). In conclusion, both clustering algorithms can be used to identify the major objects on the CL surfaces, while ISODATA clustering is more efficient than the K-means clustering for identifying the major objects on the GL surfaces.

2.6 Summary

In this chapter, the procedure for mapping major objects and the eroded plates located on the levee surfaces is introduced using the geometric information obtained from the LiDAR data and the spectral information obtained from the multispectral orthoimages. Multiple geometric and spectral analysis techniques, such as the breakline detection method, morphological filtering, 2-D interpolation method, median filtering, clustering algorithms (K-means clustering and ISODATA clustering), slope difference analysis and elevation and area analysis are employed to identify various major objects and eroded plates on the levee surfaces. As a result, all features located on the levee surfaces are identified by using the steps in the model introduced.
CHAPTER 3: MAPPING LEVEE LINES

3.1 Background

This chapter discusses a procedure for mapping levee lines using the cluster results generated in Chapter 2, the geometric information obtained from LiDAR data and the spectral information obtained from the image sources. Previous research on mapping levee/dike lines has been carried out using only LiDAR data (Brügelmann, 2000; Brzank et al., 2008). Levee line locations are generally determined by considering the surroundings, geometric patterns and major objects on levee surfaces. Hence, using LiDAR data alone is limited to identifying the levee lines located on levee surfaces. This research considers not only the geometric parameters, but the spectral parameters for identifying levee lines as well. In this chapter, the three baselines (the cluster boundaries extracted from the identified clusters, the edges extracted from the multispectral images and the plate boundaries extracted from the LiDAR DSM) are generated from different sources. Then, using the judgment test, we select one baseline as the levee line segment located on the levee surface. Figure 3.1 shows a diagram of the procedure for mapping levee lines.
In the diagram shown in Figure 3.1, the cluster boundaries are generated from the identified clusters using the modified convex hull algorithm. The edges are extracted from the images using the Canny operator. The plate boundaries are generated from the levee's top and slope plates using the modified convex hull algorithm and spline function. The two baselines are then selected from the three baselines; the plate boundaries are extracted in all levee systems; and the other baseline type is selected based on the major objects on the levee's surface. After the two baselines are selected, the judgment test is implemented to choose the most suitable levee line segment on the levee's surface. As a result, the levee lines consisting of multiple baselines are generated in all levee systems having various
levee surfaces.

3.2 Generating the cluster boundaries

This section introduces a procedure for extracting cluster boundaries from the clusters identified in Chapter 2. Since each cluster consists of the point group, the modified convex hull algorithm (Sampath et al., 2007) is employed to extract the cluster boundaries. Before explaining the modified convex hull algorithm, a description of the procedure to obtain the convex hull algorithm follows (Lee, 2012).

Step 1. The left-most point belonging to the boundary is found, and defined as starting point P.

Step 2. A line segment is created from P to all other points. The clockwise angles between the vertical axis from P and all the segments are calculated. The segment with the smallest angle is selected as part of the convex hull. The next point of the generated convex hull would be the connected point (CP).

Step 3. The line segments from the CP to all other points, except the points that belong to the convex hull, are created. The clockwise angles of the previous convex hull and all other segments are also calculated. The segment with the smallest angle is selected as part of the convex hull and the point connected to this segment would be the next point on the convex hull.

Step 4. Step 3 is repeated until it returns to the starting point.

The modified convex hull algorithm procedure differs from the convex hull algorithm procedure, and is described below (Sampath et al., 2007; Lee, 2012).

Step 1. The left-most point of the boundary is found, and is defined as starting
Step 2. Point groups near P are found.

Step 3. Using the convex hull algorithm, continue to search for the boundary point among the point groups. The line segment made by the selected point and P does not intersect with existing line segments.

Step 4. After a new boundary point is selected, Steps 2, 3 and 4 are repeated.

Step 5. Continue the process until returned to starting point P.

Figure 3.2 shows a comparison of the procedures for the modified (right column) and traditional convex hull algorithms (left column).

Figure 3.2 Comparison of the procedures of the modified (right column) and traditional convex hull algorithms (left column) (Sampath et al., 2007).
As seen in Figure 3.2, the boundary generated by the modified convex hull algorithm is significantly different from the boundary generated by the traditional convex hull algorithm. The latter generates the boundary for surrounding all of the points, while the modified convex hull algorithm generates the boundary that comes into close contact with this point cloud's boundary point. Figure 3.3 shows an example of the soil road boundaries generated by the modified convex hull algorithm.

![Soil road boundaries](image)

Figure 3.3 Example of the soil road boundaries generated by the modified convex hull algorithm.

As seen in Figure 3.3, the modified convex hull algorithm provides a good description of the objects' boundaries by tracing their boundary points.
3.3 Generating the edges

This section introduces the procedure for extracting the edges from multispectral images. In general, high resolution image sources have higher horizontal accuracy than LiDAR data (Liu et al., 2009). Additionally, since the edges extracted from the high resolution image sources consist of seamlessly connected pixels, they are useful when describing the detailed shapes of features. As seen in Figures 1.7 and 1.9, two objects having different spectral patterns are located along the boundaries of the top and slope plates. The given multispectral images provide four bands: three visible bands (red, green and blue) and one invisible band (Near Infrared (NIR)). Each band provides different spectral information. From these four bands, we select the appropriate one for extracting the edges, including the thematic information about major objects on the levee's surfaces. Multiple assumptions are useful for selecting the appropriate band to extract the edges, which includes thematic information about the major objects on the levee surfaces. They are described as follows.

Assumption 1. In general, the visible structures constructed by humans are well recognized in the visible bands provided by the multispectral imaging systems (Aligarh Muslim University, 2013; Jensen, 2006; Wolf, 2010). Since levees are man-made structures, we assume that the boundaries of multiple objects on the levee's surfaces are better recognized in the visible bands versus the NIR band.

Assumption 2. Since the red band has the longest wavelength among the three visible bands, it is the most insensitive to noises caused by atmospheric
scattering, etc., among the three visible bands (Goforth, 2006; Jensen, 2006).

Assumption 3. Figure 3.4 shows the spectral reflectance curves for various materials in the visible and infrared ranges. In the multispectral images, the blue band has a 400–580 nm wavelength, the green band has a 500–650 nm wavelength, the red band has a 590–675 nm wavelength and the NIR band has a 675–850 nm wavelength (Intergraph, 2013).

![Figure 3.4 Spectral reflectance curves for various materials in the visible and infrared ranges (Horing, 2013).](image)

Figure 3.4 shows that the reflectance differences between the major objects (asphalt, concrete, soil, grass, etc.) on the levee surfaces are significant in the red band range.

To proving the above assumptions, we show the differences between the intensity values of the samples located on CL surfaces – the asphalt roads, concrete
blocks, grass blocks and ground, in the four bands, and the difference between the intensity values of the samples located on the GL surfaces - the gravel roads, natural blocks and ground in the four bands. Figure 3.5 show the NIR, red, green and blue bands showing the CL surfaces and the location of selected samples of asphalt roads, concrete blocks, grass blocks and ground in the four images. Table 3.1 shows the difference of the intensity values between the samples located on the CL surfaces in the four bands. Figure 3.6 shows the NIR, red, green and blue bands showing the GL surfaces and the location of selected samples of gravel roads, natural blocks and ground in the four images. Table 3.2 shows the difference of the intensity values between the samples located on the GL surfaces in the four bands.

(a) NIR band image.

Figure 3.5 Four band images showing the CL surfaces and the locations of the samples of each object (Continued).
Figure 3.5 continued

(b) Red band image.

(c) Green band image.

Figure 3.5 continued
Figure 3.5 continued

(d) Blue band image.

Table 3.1 Differences of the intensity values of the samples located on the CL surfaces in the four bands.

<table>
<thead>
<tr>
<th></th>
<th>Between the asphalt roads and the concrete blocks</th>
<th>Between the asphalt roads and the grass blocks</th>
<th>Between the concrete blocks and the ground</th>
<th>Between the grass blocks and the ground</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIR</td>
<td>50.8</td>
<td>47.3</td>
<td>52.3</td>
<td>36.3</td>
</tr>
<tr>
<td>Red</td>
<td>72</td>
<td>92</td>
<td>88.2</td>
<td>38</td>
</tr>
<tr>
<td>Green</td>
<td>57.7</td>
<td>85.6</td>
<td>76.6</td>
<td>29.5</td>
</tr>
<tr>
<td>Blue</td>
<td>40.9</td>
<td>84.3</td>
<td>60.8</td>
<td>22.8</td>
</tr>
</tbody>
</table>
Figure 3.6. Four band images showing the GL surfaces and the locations of the samples of each object (Continued).
Figure 3.6 continued

(c) Green band image.

(d) Blue band image.
Table 3.2 Differences of the intensity values of the samples located on the GL surfaces in the four bands.

<table>
<thead>
<tr>
<th></th>
<th>Between the gravel roads and the natural blocks</th>
<th>Between the natural blocks and the ground</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIR</td>
<td>66.2</td>
<td>36</td>
</tr>
<tr>
<td>Red</td>
<td>120.8</td>
<td>91.3</td>
</tr>
<tr>
<td>Green</td>
<td>112.1</td>
<td>69.2</td>
</tr>
<tr>
<td>Blue</td>
<td>83.6</td>
<td>32.6</td>
</tr>
</tbody>
</table>

Figures 3.5 ~ 3.6 and Tables 3.1 ~ 3.2 show that the spectral differences between the two different objects on the various levee surfaces are more easily recognized in the red bands than the other three. Hence, in this research we use the red band image to extract the edges located between the major objects on the various levee surfaces. In general, edges extracted from the image sources is suitable for mapping the levee lines located on the levee surfaces having the boundaries of the two different objects. In this research, mapping the levee lines located on the levee surfaces having the man-made feature such as the asphalt / gravel roads is carried out by using the edge detection method. Hence, the next step is to extract the edges from the red band image by using the edge detection method. The edge detection method is an image-processing technique to identify sudden changes or discontinuities in the digital images, and there are multiple fundamental steps, such as the image-smoothing step for noise reduction, edge point detection step, edge localization step, etc. (Gonzalez and Woods, 2008). There are the various operators for edge detection such as the Marr-Hildreth operator, the Roberts operator, the Prewitt operator, the Sobel edge operator, etc. In this research, the Canny operator is used to extract the edges from the images because of its superior performance over other operators. Multiple
steps are included in the Canny operator, and each is illustrated as follows (Gonzalez
and Woods, 2008):

Step 1. Smooth the input image with a Gaussian kernel: In this step, the input
image is smoothed by convolving it with a Gaussian kernel made by a given
sigma value (δ). This operation is explained in the following equation.

\[
F_{S}(x, y) = G(x, y) * F(x, y), G(x, y) = e^{-\frac{x^2 + y^2}{2\delta^2}}
\]

where, \(F(x,y)\) denotes the input image, \(G(x,y)\) denotes the Gaussian function
and \(F_{S} x,y\) denotes a smoothed image.

Step 2. Compute the gradient magnitude and angle of each pixel: In this step,
the derivatives in both the x and y direction are computed; those results are
used to compute the gradient magnitude and direction of each pixel in the
image. This operation is explained in the following equations.

\[
M(x, y) = \sqrt{G_x^2 + G_y^2}
\]

\[
\alpha(x,y) = \tan^{-1}\frac{G_x}{G_y} \text{ with } G_x = \frac{\partial F_{S}}{\partial x} \text{ and } G_y = \frac{\partial F_{S}}{\partial y}
\]

where \(M(x, y)\) denotes the gradient magnitude and \(\alpha x,y\) denotes the
direction (angle) of each pixel.

Step 3. Apply non-maximum suppression to the gradient magnitude image to
trace along the edge in the edge direction, and produce thin lines in the output
image. In this step, the pixels are suppressed if they do not constitute a local
maximum.

Step 4. The final step is to threshold GN \((x,y)\), the non-maximum suppressed
image, to reduce false edge points. In this step, hysteresis thresholding is
employed by using two thresholds: TH (high threshold) and TL (low threshold).

a) If GN(x,y) is higher than the TH, it is accepted as an edge pixel.

b) If GN(x, y) is lower than the TL, then it is rejected.

c) If GN(x,y) is between the TH and TL, then it will be accepted only if it is connected to a pixel that is above the TH.

The major parameters of the Canny operator are the sigma value used for the Gaussian kernel, the TH and the TL. In this research, the major parameters used to extract the levee edges are selected based on an empirical analysis, and the sigma value is set as 0.3, the low threshold is set as 0.1 and the high threshold is set as 0.2. Figure 3.7 shows the operations of the edge detection from the red band image by the Canny operator ((a) original red band image and (b) detected edges from the red band image by the Canny operator).

![Image of edge detection with original red band image and detected edges]

(a) Original red band image  
(b) Detected edges from the red band image by the Canny operator

Figure 3.7 Operation of the edge detection from the red band image by the Canny operator.
Figure 3.7 shows that numerous edge segments are extracted from the red band image by the Canny operator; hence, we need to select the edge segments located between the objects on the levee surfaces. The cluster samples identified in Chapter 2 are used to select the edge segments. Because of the irregular registration errors between the LiDAR points and the image sources, the cluster boundary points selected from the LiDAR data may not directly correspond to the edges representing the boundary between the two objects (Awrangjeb et al., 2012). Hence, in this research the edge segments representing the boundaries of the objects are selected by the following semi-automatic methods.

Step 1. The boundary points of each object (the road or the slope block) are generated by using the modified convex hull algorithm.

Step 2. The buffer is generated from the boundary point group. Considering the average point density (1.5 points / m²) of the given LiDAR data and the pixel resolution (25 cm) of the given image source, the buffer distance is set as 1 m to include at least one pixel of the image and one point of the LiDAR data in each buffer.

Step 3. The edges located within the buffer are selected as the edge segment representing the boundaries of the two different objects. Figure 3.8 shows the operation of the edge selection by using the boundary point group.
In Figure 3.8, the edge segment that consists of red pixels is selected due to its location within the buffer, while the edge segment that consists of blue pixels is not selected due to its location far from the buffer. If multiple edges are located within the buffer, the edge located closest to the boundary point group is selected. After the edge segments are selected, the straight lines are manually generated to connect the disconnected edge segments and construct the all edges. Figure 3.9 shows an example of the constructed edges representing the boundaries of the gravel road.
3.4 Generating the plate boundaries

The plate boundaries are generated from the LiDAR points representing the boundaries of the levee top and slope plates generated in Chapter 2. The levee lines of levees constructed in South Korea are designed to have smooth-curve patterns (Lee, 2010). Hence, we create the plate boundaries having the smooth-curve patterns using the boundary points of the top and slope plates. First, the boundary points of both plates of the top and slope plates are extracted from the LiDAR points by using the modified convex hull algorithm. In this research, the smoothing spline is used to create the levee lines having smooth-curve patterns and to reduce the zigzag patterns caused by the noisy points included in the boundary. The smoothing spline uses the spline function by choosing the appropriate smoothing parameter (Mathworks, 2013).
The smoothing spline $s$ minimizes the residual sum of squares by using the following equation (Mathworks, 2013; Pollock, 1993).

$$ p \left( \sum (y_i - s(x_i))^2 \right) + (1 - p) \int s''(x)^2 \, dx $$

(3-4)

where $p$ is a smoothing parameter, $s(x)$ is the smoothing spline function and $(x_i, y_i)$ is a sequence of observations. The value of $p$ is defined between 0 and 1, and $p = 0$ generally produces a linear polynomial fit to data, while $p = 1$ generally produces a natural cubic polynomial fit that passes through all data points (Mathworks, 2013). Hence, the curves generated by using smoothing parameters with high value have relatively sharp-curve patterns, while the curves generated by using smoothing parameters with low value have relatively smooth-curve patterns close to the straight line. To generate lines having the smoothing curve patterns, we choose low values for the $p$ based on an empirical analysis. Figure 3.10 shows the comparison of the plate boundaries by the smoothing spline function using different $p$ values with the reference lines ((a) plate boundary points (red dots) extracted by the modified convex hull algorithm, (b) generated plate boundaries (green lines) by choosing the $p$ values as 0.5 and the reference lines (yellow lines), and (c) generated plate boundaries (red lines) by choosing the $p$ values as 0.1 and the reference lines (yellow lines)).
(a) Plate boundary points (red dots).

(b) Generated top plate boundaries (green lines) by choosing the $p$ values as 0.5 and the reference lines (yellow lines).

(c) Generated top plate boundaries (red lines) by choosing the $p$ values as 0.1 and the reference lines (yellow lines).

Figure 3.10 Comparison of the plate boundaries generated by the smoothing spline function using different $p$ values with the reference lines.
Figure 3.10 shows that the plate boundaries generated by choosing the smoothing parameters 0.5 and 0.1 have smooth-curve patterns. However, the plate boundaries generated by choosing smoothing parameter 0.5 generate relatively sharp-curve patterns due to the noisy boundary points, while the plate boundaries generated by smoothing parameter 0.1 have relatively smooth-curve patterns and are more close to the reference lines. Hence, we choose 0.1 as the smoothing parameter to create the levee lines having smooth-curve patterns from the boundary point sets by using the smoothing spline function.

### 3.5 Judgment test for selection of the levee line segments

This section introduces a judgment test for selecting the levee line segment on various levee surfaces. One baseline is selected from multiple baselines by the judgment test. Each baseline has different characteristics for representing the boundaries of various objects, as follows.

Edges: The edges are extracted from the image sources by using difference intensity values of pixels located between two objects. As seen in Figures 3.5 and 3.6, the intensity differences between the man-made features and the non-man-made features are significant, and we assume that their boundaries are well described by using the edges. Hence, the edges are selected as the baselines for describing the boundaries of the gravel road, the asphalt road on the levee top plates, and the boundaries of the slope plates. However, the edges are not detected on the areas where object boundaries are not clearly
recognized in the image. The edges located on these areas are constructed manually.

Cluster boundaries: The cluster boundaries are extracted from the identified clusters. In this research, they are used as baselines and represent the boundaries of non-man-made objects such as soil roads with edges that are not well described by using the edge detection methods due to low contrast images showing the areas where these objects are located (see Figure 3.3). Hence, the cluster boundaries are selected as the baselines for describing the boundaries of the soil road on the top plates by tracing their boundary points.

Plate boundaries: Plate boundaries are extracted from the LiDAR data, and they describe the levee shapes by using only geometric parameters. Since they do not consider the spectral parameters, they can be extracted in all levee surfaces regardless of the major objects on them. However, since the plate boundaries are generated by using only the geometric parameters, they are limited to describing the boundaries of what is considered the major object on the levee surfaces.

In this research, two baselines are selected and compared in order to select the most suitable levee line segments using the judgment test on all levee surfaces. The type of baseline selected is determined based on the major objects on the levee surfaces. Table 3.3 shows the major objects on the levee surfaces and the types of the selected baselines that are selected and compared.
Table 3.3 Major objects on the levee surfaces and the types of the baselines that are selected and compared.

<table>
<thead>
<tr>
<th>The major objects</th>
<th>The baseline types for the judgment test</th>
</tr>
</thead>
<tbody>
<tr>
<td>The asphalt / gravel roads on the levee top / berm plates</td>
<td>The plate boundaries and the edges</td>
</tr>
<tr>
<td>The soil road on the levee top / berm plates</td>
<td>The plate boundaries and the cluster boundaries</td>
</tr>
<tr>
<td>The levee slope plates and the grounds</td>
<td>The plate boundaries and the edges</td>
</tr>
<tr>
<td>Any areas where the edges or the cluster boundaries are not extracted</td>
<td>The plate boundaries</td>
</tr>
</tbody>
</table>

Table 3.3 shows that the plate boundaries are used as the main baselines in all levee surfaces, and other baselines, such as the cluster boundaries or the edges, are used partially based on the types of major objects on the levee surfaces. As seen in Table 3.3, the two different baselines are selected separately on various levee surfaces. The comparison of the two selected baselines is then carried out using the judgment test to select one as the most suitable levee line segment on the levee surface. The judgment test consists of the two sub tests, Test 1 is implemented to judge the types of the terrains where the baseline is located, and carried out as follows.

Step 1. The buffer is generated from each baseline to estimate the types of terrain on the surfaces. Considering the average point density (1.5 points / m²) of the given LiDAR data, the buffer distance is set as 2 m to include at least two LiDAR points in each buffer.

Step 2. Compute the average elevation difference (T) between the buffer zones using the LiDAR points located in each buffer zone. The T value is calculated by the following equation.
\[ T = A_{\text{top}} - A_{\text{toe}} \]  

where \( A_{\text{top}} \) denotes the average elevation of the LiDAR points located in the top direction zones, and \( A_{\text{toe}} \) denotes the average elevation of the LiDAR points located in the toe direction zones. Figure 3.11 shows the operation of Test 1 by calculating the T value using \( A_{\text{top}} \) and \( A_{\text{toe}} \) values (red dots: the LiDAR points located in the top direction zone, and the blue dots: the LiDAR points located in the toe direction zone).

![Figure 3.11 Operation of Test 1 performed by the judgment test.](image)

Step 3. The baseline suitable for the levee top line should be located on the upward slope terrains and the baseline suitable for the levee toe lines should be located on the downward slope terrains. If the baseline is located on the flat terrains, we assume that the baseline has low priority to be selected as the
levee top or toe line. The T value is used to judge the types of terrains where the baseline is located. If the baseline is located on flat terrains, the difference between the A_top and the A_toe should be small. Based on an empirical analysis, the baseline that has a T value smaller than 0.1 is identified as the line located on the flat terrain and has less priority than the baseline that has a T value higher than 0.1.

Step 4. If the T values of both baselines are higher than 0.1, Test 2 is implemented to select the best suitable levee lines on the levee top and toe by comparison of the elevations between the two baselines. Among the baselines that are located on the levee top, the baseline that has higher average elevation is selected as the levee top line segment. And among the baselines that are located on the levee toe, the baseline that has lower average elevation is selected as the levee toe line segment. Figure 3.12 shows operation of Test 2 by comparison of the average elevation between the two baselines (Baseline 1: blue dots and Baseline 2: red dots). In the left column of Figure 3.12, Baseline 1 (blue dot) is selected as the levee top line because it is higher elevation than the elevation of Baseline 2 (red dot), and in the right column of Figure 3.12, Baseline 2 (red dot) is selected as the levee toe line because it is lower elevation than that of Baseline 1 (blue dot).
In Step 4, if the T values of both baselines are lower than 0.1, we assume that both baselines are located on the flat terrains. In this case, the baseline that has higher T value is selected as the levee lines, since we assume that the selected baseline is close to the slope terrains than the non-selected baseline. And, if one baseline has a T value higher than 0.1 and the other baseline has a T value lower than 0.1, the first baseline is also selected based on the same assumption ahead.

### 3.6 Experiment

In this section, an experiment is described in which the levee lines located on the various levee surfaces are generated through the procedure introduced in this chapter. First, the plate boundaries are generated in all levee surfaces. Second, the major objects on the levee top and slope plates are identified by comparing the number of samples of each cluster on the plate. For a detailed examination of the
research, the major objects are identified in 10 m intervals. Then two baselines, the plate boundaries and the other baseline, are selected based on the major objects on the levee surfaces. The judgment test is carried out to select one baseline as the best suitable levee line segment on the levee surface. By using these methods, the generated levee top or toe lines on the levee surfaces having the same major objects can consist of two types of baselines. Figure 3.13 shows the edges (blue lines) and the plate boundaries (red lines) constitute the levee top and toe lines on the CL having the asphalt road on the top plate and the concrete block on the riverside slope plate. Figure 3.14 shows the cluster boundaries (green lines), the edges (blue lines) and the plate boundaries (red lines) that constitute the levee top and toe lines on the GL having the soil road on the top plate and the natural block on the riverside slope plate.

Figure 3.13 Edges (blue lines) and the plate boundaries (red lines) that constitute the levee top and toe lines on the CL.
3.7 Summary

This chapter introduces new methods for generating levee lines using the LiDAR data and multispectral orthoimages. The levee lines generated consist of three baselines (the edges extracted from the images, the cluster boundaries extracted from the identified clusters and the plate boundaries extracted from the LiDAR data) generated from the different sources. The judgment test is implemented in order to select one baseline as the most suitable levee line segment on the various levee surfaces. As a result, the levee lines that consist of multiple baselines are generated on various levee surfaces.
CHAPTER 4: MAPPING LEVEE INFORMATION SYSTEMS

4.1 Background

This chapter discusses a procedure for mapping levee information systems showing the levee segments with failure risks. These information systems are established using the results derived in Chapters 2 and 3. To map levee information systems, the levee top lines are shown on each system, and the segments of the levee top lines located in the areas having failure risks are shown with specific colors (red, yellow, blue and green). In this research, the types of levee failure risks are divided into the three categories: risk of overtopping, risk of top failure and risk of slope failure. The level of levee failure risks are divided into the four categories: high, middle, low and safe. Levee failure is defined as the situation occurring when the levee becomes unstable and allows flooding (USACE, 2013). In general, levee failure causes broken levee segments that eventually lead to an opening for water to flood the levee's landward side (Ohio Department of Natural Resources (ODNR), 2011). Figure 4.1 shows an example of levee failures occurring in California.
In general, levee conditions are dynamic and are relevant to flood risks (USACE, 2013). Assessing levee stability is important for evaluating the failure risks and advising the decision-maker about how to reduce these risks. USACE inspects the stability of levee systems in the U.S. (USACE, 2013). Casas et al. (2012) assessed the stability of levees in the Sacramento River via one-dimensional analysis using the geometric parameters derived from the LiDAR data. However, the ground surveying method is not efficient for assessing levee stability because of the extended length of levee systems. Also, using only LiDAR data limits identifying multiple levee failure
risks occurring on surfaces with various components.

This chapter introduces new methods for mapping levee information systems and shows levee segments that, upon evaluation, were found to have failure risks. Each risk is measured separately, and the segments of the levee top lines located on terrain having levee failure risks are shown with specific colors (red, yellow, blue and green) in the constant interval. This chapter also illustrates one example of the established levee information system by using the suggested methods.

4.2 Types of the levee failure risks

In this research, types of levee failure risks are divided into three categories: risk of overtopping, risk of top failure and risk of slope failure. Each risk type is measured separately using the results derived in Chapters 2 and 3. Each risk is defined in the following paragraphs.

① Risk 1: Risk of overtopping

In general, the levee with a height less than the threshold is at risk for overtopping. Overtopping occurs when the flood water's level is greater than the levee's height. When overtopping occurs, water flows over the levee top, undercuts the levee, and eventually causes the levee to be breached or to collapse (California Water Science Center, 2013). Figure 4.2 shows an example of overtopping occurring on the Mississippi River levee.
To assess the risk of overtopping, the minimum height of the levee should be determined. In general, the minimum height of the levee should be higher than the threshold calculated using the levee’s water surface elevation and the levee top’s freeboard height beyond its maximum water surface elevation. The minimum levee height is calculated using the following equation (Casas et al., 2012; MOLIT, 2009):

\[ MH \geq W + F \]  \hspace{1cm} (4-1)

where the MH denotes the minimum height of the levee, the W denotes the maximum water surface elevation of the levee, and the F denotes the freeboard. In this research, the height of the levee is obtained from the elevation of the top plates generated in Chapter 2, and information about the levee’s maximum surface water elevation and freeboard are provided by the WAMIS website (2013) and the MOLIT (2009). Hence,
the top segment, with a height lower than the MH value, is determined to have a risk for overtopping.

② Risk 2: Risk of top failure

To prevent levee collapses from flooding, the levee top should be of an appropriate width to secure refuges during flood events and provide space for human activities such as public transportation. In general, the top segment with an average width more narrow than appropriate is hazardous to humans and equipment during wet weather events (Wellborn and Brunson, 1997). The threshold for assessing the risk of top failure is calculated by using the following equation.

\[
AW \geq MW
\]  

(4-2)

where the AW denotes the average width of the levee top calculated along the 10 m intervals, and the MW denotes the minimum width of the top segment. For assessing the risk of top failure, the average width of the top segment is calculated by measuring the distance between the two levee top lines, generated in Chapter 3, as well as the minimum width of the levee top according to the construction laws of South Korea. Levees constructed in South Korea have 4 ÷ 7 m widths on their tops (MOLIT, 2009). In general, these levees, located parallel to the main course of a river, are wide on their top plates, and levees located parallel to a small stream have top plates that are shorter (MOLIT, 2009). Since all of the levees in this study area are parallel to the main course of the Nakdong River, the MW is set as 7 m. Hence, the top segment, with an average width shorter than 7m, is evaluated to be at risk for top failure.
③ Risk 3: Risk of slope failure

Instability of the slope plates causes multiple problems related to levee failure, such as sliding, etc. In general, the flattened slopes reduce gravity force causing failures and increase resistance to sliding, while steep slopes generally tend to increase the risk of sliding (USACE, 2000). Figure 4.3 shows an example of damage to levee slope plates.

Figure 4.3 Example of the damage to levee slope plates (USACE, 2013).

In this research, we implement the assessment of the risk of slope failure by using the average slope of the slope segments and the areas of eroded plates located on the slope segments. In Chapter 2, the eroded areas are identified by their elevation difference and area analysis. To assess the risk of slope failure on the slope segments, two thresholds are used. Threshold 1 is used to assess the risk of slope failure by
using the average slope of the slope segments, and Threshold 2 is used to assess the risk of slope failure by using all of the eroded areas on the slope segments. Threshold 1 is determined by using the following equation.

\[ T_1 \leq \text{Min}_S \text{ OR } \text{Max}_S \leq T_1 \]  \hspace{1cm} (4-3)

where the \( T_1 \) denotes Threshold 1, the \( \text{Min}_S \) denotes the minimum slopes of the slope segment, and the \( \text{Max}_S \) denotes the maximum slopes of the slope segment. The levees constructed in South Korea are designed to have 18.43° to 33.69° on their slope plates (MOLIT, 2009). We assume that the slope segments are at risk for slope failure if their average slopes are lower than 18.43° and higher than 33.69°. Hence, the \( \text{Min}_S \) is set as 18.43° and the \( \text{Max}_S \) is set as 33.69°. Threshold 2 is determined by using the following equation.

\[ T_2 \geq \text{EA} \]  \hspace{1cm} (4-4)

where \( T_2 \) denotes Threshold 2, the \( \text{EA} \) denotes all eroded areas on the slope segment. We assume that the slope segment that includes eroded areas greater than \( T_2 \) has the risk of slope failure. There is no precise rule for defining slope failure risk in eroded areas. In general, the slope segment that includes large eroded areas is at high risk for slope failure (USACE, 2006). Based on an empirical analysis, the \( \text{EA} \) is set as 100. Hence, we assume that the slope segment that includes more than 100 m² of the eroded area is at risk for slope failure.

4.3 Procedure for mapping levee information systems

This section describes a procedure for mapping levee information systems
using the risk factors defined in Section 4.2. Figure 4.4 is a flowchart showing the mapping procedure for the levee information system. The procedure has multiple steps.

![Figure 4.4 Flowchart showing the procedure for mapping the levee information system.](image)

First, the levee top lines are generated in each levee system. One levee top line is generated between the top plate and the riverside slope plate, and the other is generated between the top plate and the landside slope plate. The constant intervals are then set on each levee top line. Historically, the ground surveying method has been used to assess levee stability along 50~100 m intervals (MOLIT, 2009). Hence, the 100 m intervals are also set on the levee top lines to assess the levee failure risks on each segment. After the constant intervals are set on the levee top lines, each risk
(Risks 1, 2 and 3) is measured separately on each levee segment. To measure the levee failure risk on each levee system, we identify each system in the study area. Eight levee systems are selected to establish the levee information systems. Figure 4.5 shows the locations of the eight levee systems in the study area.

![Figure 4.5 Locations of the eight levee systems in the study area.](image)

To measure Risk 1 on each levee, we use the information about the maximum water surface elevation and the freeboard of each system provided by the WAMIS (2013) website and the MOLIT (2009). Table 4.1 shows the data about the maximum water surface elevation of each levee in the study area.
Table 4.1 Information about the expected water surface elevation of each levee in the

study area (WAMIS, 2013).

<table>
<thead>
<tr>
<th>Levee ID</th>
<th>The maximum water surface elevation of each levee (m)</th>
<th>Levee ID</th>
<th>The maximum water surface elevation of each levee (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Levee 1</td>
<td>13.43</td>
<td>Levee 5</td>
<td>11.49</td>
</tr>
<tr>
<td>Levee 2</td>
<td>12.98</td>
<td>Levee 6</td>
<td>11.54</td>
</tr>
<tr>
<td>Levee 3</td>
<td>12.65</td>
<td>Levee 7</td>
<td>11.54</td>
</tr>
<tr>
<td>Levee 4</td>
<td>12.34</td>
<td>Levee 8</td>
<td>11.54</td>
</tr>
</tbody>
</table>

The height of the freeboard of the levee systems located in the study area is set as 2 m (MOLIT, 2009). Using the above information, the minimum height [MH value in equation (4.1)] of each levee system is calculated. The top segments, with average elevations lower than the MH value, are defined as the areas having Risk 1 (overtopping). To measure Risk 2 (top failure) on each levee system, the average width between the two levee top lines is measured on each top segment. The top segments with an average width lower than 7 m are defined as the areas having Risk 2. To measure Risk 3 (slope failure) on each levee system, the average slope of each slope segment and all eroded areas on each slope segment are measured. The slope segments with average slopes higher the Max_S or lower than the Min_S, or with slope segments, including the entire eroded areas, greater than the EA are defined as the areas having Risk 3. After each risk is measured separately on each top or slope segment, the level of the levee failure risk on each area, including the top and one side slope segments in the same interval, is determined. If no risk is detected in the area, that area is defined as safe from levee failures. If one type of risk is detected in an area, the area is defined as having low-level risk for levee failure. If two or three types
of risks are detected in an area in the same interval, the terrain is defined as having middle- or high-level risk of levee failure. The levee top lines located on the areas safe from levee failures are shown in green; those located in the areas having a low level risk for levee failures are shown in blue; located in the areas having middle level risk of levee failure are shown in yellow; and located in the areas having a high level risk of levee failure are shown in red. Figure 4.6 illustrates the procedure for mapping the levee information system.

Figure 4.6 Operation showing the procedure of mapping the levee information system.

In Figure 4.6, one segment of the levee top lines, located between the top plate and the landside slope plate, is shown in red because the area includes risks for overtopping, top failure and slope failure. One segment of the levee top lines, located
between the top plate and the riverside slope plate, is shown in yellow because the area includes risks for overtopping and top failure.

4.4 Example of the established levee information system

This section discusses one example of the established levee information system in the study area by using the methods introduced in this chapter. We select levee system 6, shown in Figure 4.5, to establish an example of the levee information system. Figure 4.7 shows the levee information system generated in levee system 6. To show enlarged views of the generated levee information system, the area of levee system 6 is divided into three regions: A, B and C. They are shown in Figures 4.8, 4.9 and 4.10. Table 4.2 holds the statistical results showing the stability of the levee top and slope plates in Regions A, B and C.

Figure 4.7 Levee information system generated in levee system 6.
Figure 4.8 Region A: The levee information system generated in levee system 6.

Figure 4.9 Region B: The levee information system generated in levee system 6.
Figure 4.10 Region C: The levee information system generated in levee system 6.

Table 4.2 Statistic results showing stabilities of the levee top and slope plates in Regions A, B and C.

<table>
<thead>
<tr>
<th>Area</th>
<th>Region A</th>
<th>Region B</th>
<th>Region C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major object on the top plate</td>
<td>Gravel road</td>
<td>Gravel road</td>
<td>Soil road</td>
</tr>
<tr>
<td>Major object on the slope plates</td>
<td>Natural block</td>
<td>Natural block</td>
<td>Natural block</td>
</tr>
<tr>
<td>Average elevation of the top plate (m)</td>
<td>13.21</td>
<td>13.26</td>
<td>13.09</td>
</tr>
<tr>
<td>Average width between the two levee top lines</td>
<td>4.43</td>
<td>4.21</td>
<td>4.45</td>
</tr>
<tr>
<td>Average slopes of the riverside slope plate</td>
<td>22.53</td>
<td>21.51</td>
<td>21.66</td>
</tr>
<tr>
<td>Standard deviation of the riverside slope plate</td>
<td>5.93</td>
<td>5.02</td>
<td>5.70</td>
</tr>
<tr>
<td>Average slopes of the landside slope plate</td>
<td>21.14</td>
<td>20.77</td>
<td>19.62</td>
</tr>
<tr>
<td>Standard deviation of the landside slope plate</td>
<td>7.44</td>
<td>7.86</td>
<td>8.54</td>
</tr>
</tbody>
</table>

The surfaces of levee system 6 consists of gravel roads (Regions A and B) and
soil roads (Region C) on the top plate, and natural blocks on both slope plates. Based on equations (4.1) and (4.2) and Table 4.1, the minimum height of the top plate of levee system 6 should be 13.54 m, and the minimum width of the top plate of levee system 6 should be 7 m. Table 4.2 shows that the average elevations of the top plates of the entire regions (Regions A, B and C) in levee system 6 are lower than 13.54 m, and the average widths of the top plates of the entire region are also less than 7 m. Hence, the top segments of the entire levee system 6 are evaluated to have a middle level risk for levee failure. Table 4.2 also shows that both riverside and landside slope segments are generally safe from levee failures because the average slope values of the slope plates of Regions A, B and C are in the range of the Min_S (18.43°) and the Max_S (33.69°), determined in equation (4.3). However, some landside slope segments in Region C have a low level risk of levee failures due to a large eroded area greater than T2. Figure 4.11 shows the levee top lines (in red and yellow) and the eroded plates (yellow polygons) located on the slope segments with a corresponding elevation profile.
Figure 4.11 Levee top lines shown in red and yellow and the eroded plates (yellow polygons) located on the slope segments with a corresponding elevation profile.

Figure 4.11 shows that the area evaluated to have a high level risk for levee failures includes the eroded plates (yellow polygons) on its slope segment. The elevation profile in Figure 4.11 also shows that the area has unstable surfaces on its slope segment due to the eroded plates on the surfaces. As a result, the segments of the levee top lines located on the areas having risk of overtopping and top failure are shown in yellow and the segments of the levee top lines in the areas having risk of overtopping, top failure and slope failure, are shown in red.

4.5 Levee information systems established in the entire study area

Using the methods introduced in this chapter, levee information systems are established in all levee systems of the entire study area. Figures 4.12, 4.13, 4.14, 4.15, 4.16, 4.17 and 4.18 show the levee information system established in levee systems 1, 2, 3, 4, 5, 7 and 8.
Figure 4.12 Levee information system established in levee system 1.

Figure 4.13 Levee information system established in levee system 2.
Figure 4.14 Levee information system established in levee system 3.

Figure 4.15 Levee information system established in levee system 4.
Figure 4.16 Levee information system established in levee system 5.

Figure 4.17 Levee information system established in levee system 7.
4.6 Summary

In this chapter, new methods for mapping the levee information systems are suggested using the results derived in Chapters 2 and 3. The risks of levee failures are divided into three types: overtopping, slope failure and top failure, and each is measured separately. Using the suggested method, the levee top lines located in the areas safe from levee failures or that have risks for levee failures are shown with specific colors (red, yellow, blue and green) to show the risks in each area. This chapter suggests an efficient method for acquiring the information about levee failure risks by using the information derived using remote sensing technologies.
CHAPTER 5: RESULTS AND ANALYSIS

Multiple tasks are implemented in this chapter. First, this chapter provides information about the study area and data sets used in this research. Second, this chapter discusses the general characteristics of the levee lines generated in each levee system. Third, this chapter shows the statistical results of the horizontal and vertical accuracy of the levee lines. Fourth, this chapter analyzes the accuracy of the levee lines using various factors. Fifth, comparison of the accuracy of the levee lines generated in this research with the accuracy of the levee lines generated in the historical research is carried out. Finally, estimation of the failure risks of the levee systems in the study area is carried out using the established levee information systems.

5.1 Study area and data sets

The study area for this research is a river basin in a 22 kilometer stretch of the Nakdong River, which passes through the South Korean cities of Changnyeong, Milyang and Changwon. Figure 5.1 shows an aerial view of the study area of the Nakdong River, South Korea.
The Nakdong River is the longest river in South Korea with a total length of 525 km. The annual rainfall in the study area is 1229.0 mm (MOLIT, 2009).

The reasons for choosing this area are explained as follows.

1. The availability of multiple remote sensing data sets such as LiDAR data and the multispectral aerial orthoimages that are taken at about the same time, makes this region an excellent visual site for levee mapping tasks.

2. This region suffers serious damage caused by annual flooding events (MOLIT, 2009; WAMIS, 2013). These events cause a significant loss of property in the study area. Table 5.1 shows the U.S. dollar ($) value of properties lost in the study area by annual flooding from 2006 - 2009 (WAMIS, 2013).
Table 5.1 Value of property lost due to annual flooding in the study area from 2006 - 2009 (WAMIS, 2013).

<table>
<thead>
<tr>
<th>Year</th>
<th>Value of property lost due to annual flooding in the study area ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>4,763,700</td>
</tr>
<tr>
<td>2008</td>
<td>Not indicated</td>
</tr>
<tr>
<td>2007</td>
<td>3,725,500</td>
</tr>
<tr>
<td>2006</td>
<td>8,352,000</td>
</tr>
</tbody>
</table>

The airborne topographic LiDAR data and the multispectral aerial orthoimages are used as the main data sets for this research. The LiDAR data was acquired in December 2009 using the ALTM Gemini 167 sensor at a speed of 234 kilometers per hour. The horizontal datum is International Geodetic Reference System (GRS) 1980, and the vertical datum is the mean sea level (MSL) at Incheon Bay, the vertical datum of Korean geodetic datum. The average point density of the given LiDAR data is 1.5 points / m$^2$. The horizontal accuracy is 15 cm and the vertical accuracy is 5 cm. The multispectral aerial orthoimages were acquired in January 2010 using the digital mapping camera (DMC) made by Z/I Imaging Co., Ltd., and the sensor provides four color channels (red, green, blue and NIR bands). The orthoimages are georeferenced to the Transverse Mercator (TM) Coordinate System based on the datum International GRS 1980. The ground resolution of the orthoimages is 25 cm, and the accuracy of the orthoimages is 0.12 m root mean square (RMS).

5.2 Accuracy and general characteristics of levee lines generated

To measure the accuracy of the levee lines generated in Chapter 3, 17 reference lines are generated by manual digitization. They are used to measure the
horizontal and vertical accuracy of the levee top, toe and berm lines generated in Chapter 3. Figure 5.2 shows all of the reference lines (yellow lines) generated by manual digitization.

Figure 5.2 All of the reference lines (yellow lines) generated by manual digitization.

To measure the horizontal and vertical accuracy of the levee lines generated in Chapter 3, checkpoints are generated along the reference lines. The average distance between the checkpoints is 100 m. The X and Y coordinates of the checkpoints are obtained from the orthoimages, while the Z coordinates are obtained from the LiDAR data. In this research, 140 checkpoints (Levee system 1: 28; Levee system 2: 10; Levee system 3: 20; Levee system 4: 13; Levee system 5: 28; Levee system 6: 15; Levee system 7: 13; and Levee system 8: 13) are used to measure the accuracy of the generated levee top and toe lines, and 14 checkpoints are used to measure the accuracy of the generated levee berm lines. Figure 5.3 shows the locations of all checkpoints (top: red dots; toe: yellow dots; berm: cyan dots) along the reference lines (yellow lines) in each levee system.
Figure 5.3 Locations of all checkpoints (top: red dots; toe: yellow dots; berm: cyan dots) generated along the reference lines (yellow lines) in each levee system (Continued).
Figure 5.3 continued.

Locations of all checkpoints of Levee system 4

Location of all checkpoints of Levee system 5
Figure 5.3 continued.
Figure 5.3 continued.

Locations of all checkpoints of Levee system 6

Locations of all checkpoints of Levee system 7

Locations of all checkpoints of Levee system 8

Figures 5.4 ~ 5.6 show the plate boundaries (red lines) and the edges (blue
lines) that constitute the levee lines, and the reference lines (yellow lines) in the entire region, as well as the divided regions of Levee systems 1, 2 and 3.

Figure 5.4 Plate boundaries (red lines) and the edges (blue lines) that constitute the levee lines, and the reference lines (yellow lines) in the entire region and the divided regions of Levee system 1 (Continued).
Figure 5.4 continued.

(b) Generated levee lines and the reference lines in the divided regions.
(a) Generated levee lines and the reference lines in the entire region.

Figure 5.5 Plate boundaries (red lines) and the edges (blue lines) that constitute the levee lines and the reference lines (yellow lines) in the entire region and the divided regions of Levee system 2 (Continued).
Figure 5.5 continued.

(b) Generated levee lines and the reference lines in the divided regions.

(a) Generated levee lines and the reference lines in the entire region.

Figure 5.6 Plate boundaries (red lines), cluster boundaries (green lines) and the edges (blue lines) that constitute the levee lines and the reference lines (yellow lines) in the entire region and the divided regions of Levee system 3 (Continued).
The levee lines located in Levee systems 1, 2 and 3 have similar characteristics:
Both the levee top and toe lines consist of only two baselines (the plate boundaries and the edges). The general characteristics of the levee lines located in Levee systems 1, 2 and 3 are described in Table 5.2.
Table 5.2 General characteristics of the levee lines in Levee systems 1, 2 and 3.

<table>
<thead>
<tr>
<th>Main sources that constitute the levee lines</th>
<th>Both the levee top and toe lines consist of the edges and plate boundaries. Levee berm lines consist of the edges, cluster boundaries and plate boundaries.</th>
</tr>
</thead>
</table>
| General percentage of each source in the entire levee lines | Levee top lines:  
Levee system 1: 70% (edges) and 30% (plate boundaries).  
Levee system 2: 95% (edges) and 5% (plate boundaries).  
Levee system 3 (asphalt road on the top): 90% (edges) and 10% (plate boundaries).  
Levee system 3 (gravel road on the top): 10% (edges) and 90% (plate boundaries).  
Levee toe lines: 0 ~ 5% (edges) and 95 ~ 100% (plate boundaries) in all levee systems 1, 2 and 3.  
Levee berm lines: 40% (cluster boundaries), 50% (edges) and 10% (plate boundaries). |
| General qualities of the levee lines | The edges located on the up/down slope surfaces are used as the levee top or toe lines.  
The plate boundaries located on the up/down slope surfaces where the edges are not available are used as the levee top or toe lines.  
Due to the shadows located on the toe surfaces, wave attacks by water flow and erosion on the toe surfaces, the levee toe lines generally include fewer edges than the levee top lines. |
| Significant manual jobs | Some edges are manually selected and connected to construct the edges located along the boundaries of the roads. |
| Percentage of automation works | 85% (-15%: manual selection (-5%), connection (-5%) and removal (-5%) of the unnecessary edges). |

In Levee systems 1, 2 and 3, the asphalt roads are the major objects located on the three top plates, and the gravel road is located only on one top plate of Levee system 3. Hence, the top lines of Levee systems 1, 2 and 3 consist of the edges and plate boundaries. Due to shadows on the toe surfaces, wave attacks by water flow and erosion on the toe surfaces, the levee toe lines generally include fewer edges than the top lines. The tasks to generate levee lines in Levee systems 1, 2 and 3 involve
manual labor. The most significant manual labor task is selecting the edges and connecting all of the edges located along road objects. In Chapter 3, edges longer than 5 m are selected as levee line segments. However, some edge segments in the low-contrast images are disconnected and are too short to be selected as levee line segments. Additionally, multiple edge segments are detected between different objects. Hence, manual labor is used to select the edge segments having short lengths, connect them and remove the unnecessary edges to construct entire edges. Figure 5.7 shows an example of entire edges (red lines) along road objects that are constructed manually.

(a) Original edge segments.

Figure 5.7 Example of entire edges (red lines) along road objects that are constructed manually (Continued).
In this research, each manual task occupies 5% of the entire works. Since the three significant manual jobs such as selection, connection and removal of the edge segments are included in the entire works to construct the entire edges, the percentage of the automation works in the entire works is 85% in the mapping tasks of the levee lines of levee systems 1, 2 and 3.

Figures 5.8 ~ 5.12 show the plate boundaries (red lines), edges (blue lines) and cluster boundaries (green lines) that constitute the levee lines, the reference levee lines (yellow lines) in the entire region and the divided regions of Levee systems 4, 5, 6, 7 and 8.
(a) Generated levee lines and reference lines in the entire region.

Figure 5.8 Plate boundaries (red lines), edges (blue lines) and cluster boundaries (green lines) that constitute the levee lines, and reference lines (yellow lines) in the entire region and the divided regions of Levee system 4 (Continued).
Figure 5.8 continued.

(b) Generated levee lines and reference lines in the divided regions.
(a) Generated levee lines and reference lines in the entire region.

Figure 5.9 Plate boundaries (red lines), edges (blue lines) and cluster boundaries (green lines) that constitute the levee lines, and reference lines (yellow lines) in the entire region and the divided regions of Levee system 5 (Continued).
Figure 5.9 continued

(b) Generated levee lines and reference lines in the divided regions.
(a) Generated levee lines and reference lines in the entire region.

Figure 5.10 Plate boundaries (red lines), edges (blue lines) and cluster boundaries (green lines) that constitute the levee lines, and reference lines (yellow lines) in the entire region and the divided regions of Levee system 6 (Continued).
Figure 5.10 continued

<table>
<thead>
<tr>
<th>Region A</th>
<th>Region B</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td>Region C</td>
<td>Region D</td>
</tr>
<tr>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
</tbody>
</table>

(b) Generated levee lines and reference lines in the divided regions.
Figure 5.11 Plate boundaries (red lines), edges (blue lines) and cluster boundaries (green lines) that constitute the levee lines, and reference lines (yellow lines) in the entire region and the divided regions of Levee system 7.
(a) Generated levee lines and the reference lines in the entire region.

(b) Generated levee lines and reference lines in the divided regions.

Figure 5.12 Plate boundaries (red lines), edges (blue lines) and cluster boundaries (green lines) that constitute the levee lines, and reference lines (yellow lines) in the entire region and the divided regions of Levee system 8.
The levee lines located in Levee systems 4, 5, 6, 7 and 8 have similar characteristics: 1) the slope plates consist of natural blocks (soil/vegetation), and the top plates consist of unpaved roads (gravel/soil roads); and 2) the levee top lines consist of the edges, cluster boundaries and plate boundaries, and the levee toe lines consist of the plate boundary segments and edge segments. The general characteristic of the levee lines located in Levee systems 4, 5, 6, 7 and 8 are described in Table 5.3.
Table 5.3 General characteristics of the levee lines in Levee systems 4, 5, 6, 7 and 8.

| Main sources that constitute the levee lines | Levee top lines consist of the edges, plate boundaries and cluster boundaries. Levee toe lines consist of the edges and plate boundaries. |
| General percentage of each source in the levee lines | Levee top lines: Levee system 4: 50% (cluster boundaries) and 50% (plate boundaries). Levee system 5: 10% (edges) and 90% (plate boundaries). Levee system 6: 15% (cluster boundaries), 25% (the edges) and 60% (plate boundaries). Levee system 7: 5% (cluster boundaries), 15% (edges) and 80% (plate boundaries). Levee system 8: 5% (edges), 10% (cluster boundaries) and 80% (plate boundaries). Levee toe lines: 0 ~ 5% (edges) and 95 ~ 100% (plate boundaries). |
| General qualities of the levee lines | The edges on the upslope terrains having gravel roads are used as the levee top lines. The cluster boundaries on the upslope terrains having soil roads are used as the levee top lines. The plate boundaries located on the up/downslope terrains where slopes change sharply are used as the levee top or toe lines. Due to damage from the water flow and erosion occurring on the toe surfaces and low contrast images, the levee toe lines include fewer edges than the levee top lines. |
| Significant manual jobs | On some top areas, the major object is manually determined to select the baselines. |
| Percentage of Automation works | 80% (-5%: manual decision of the main objects on the top surfaces; -15%: manual selection (-5%), connection (-5%) and removal (-5%) of the unnecessary edges). |

In Levee systems 4, 5, 6, 7 and 8, the major objects of the top surfaces are unpaved roads that consist of gravel roads and soil roads. Hence, the levee top lines on the unpaved roads consist of the plate boundaries, cluster boundaries and edges. And the levee toe lines consist of the plate boundaries and edges. Due to the
characteristics of the toe surfaces that are the same as the toe surfaces of Levee systems 1, 2 and 3, the levee top lines also include more edges than the levee toe lines. The tasks for mapping the levee lines in Levee systems 4, 5, 6, 7 and 8 also require multiple manual jobs. The most significant manual job is to decide on the major objects on the top surfaces to select the type of baseline. In Chapter 3, the cluster that has the maximum number of samples is selected as the major object on the levee surface. However, gravel surfaces are easily converted into the soil/vegetation surfaces because they are unpaved; hence, the major object cannot be easily determined by comparing the number of cluster samples on the top surfaces where gravel, soil, and vegetation samples are randomly distributed. To select the baseline type, the major object is manually determined on the top surfaces where it cannot be easily determined by comparing the number of cluster samples. Figure 5.13 shows the edges (blue lines) selected as the baseline and located on the top surfaces where the major object is manually determined to be a gravel road.
(a) The three clusters (gravel: cyan dots, soil: orange dots and vegetation: green dots) on the top surfaces.

(b) The edges selected as the baseline.

Figure 5.13 Edges (blue lines) selected as the baseline on the top surfaces where the major object is manually determined to be a gravel road.

As seen in Figure 5.13, the baseline types are manually determined on some top surfaces where the major objects are not well distinguished by comparing the number of cluster samples. Since the other manual jobs, such as selection, connection and removal of the edge segments, are also included in the entire works to construct the entire edges, the percentage of the automation works in the entire works is 80% of
the mapping tasks of the levee lines of levee systems 4, 5, 6, 7 and 8.

The horizontal and vertical accuracy of the generated levee lines are obtained by measuring the shortest horizontal and vertical distances from the checkpoints on the reference lines to the generated levee lines. To save space, the accuracy measured at Levee systems 2 and 3, Levee systems 4 and 5, Levee systems 6, 7 and 8 are merged to calculate the statistical results. Table 5.4 summarizes the statistical results of the horizontal and vertical accuracy of the generated levee lines in the levee system groups. The outliers are detected by using the 3 sigma rule, and indicated using yellow in Table 5.4.
Table 5.4 Statistical results of the horizontal and vertical accuracies of the generate levee lines in the levee systems.

<table>
<thead>
<tr>
<th></th>
<th>Levee Top</th>
<th>Levee Toe</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Horizontal</td>
<td>Vertical</td>
</tr>
<tr>
<td></td>
<td>Distance (m)</td>
<td>Distance (m)</td>
</tr>
<tr>
<td>Levee system 1</td>
<td>Average</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td>St. Deviation</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>0.39</td>
</tr>
<tr>
<td>Levee systems 2 and 3</td>
<td>Average</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>St. Deviation</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>0.39</td>
</tr>
<tr>
<td>Levee systems 4 and 5</td>
<td>Average</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>St. Deviation</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>0.20</td>
</tr>
<tr>
<td>Levee systems 6, 7 and 8</td>
<td>Average</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>St. Deviation</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>0.22</td>
</tr>
<tr>
<td>Levee berm</td>
<td>Average</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>St. Deviation</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>0.1</td>
</tr>
<tr>
<td>Total</td>
<td>Average</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>St. Deviation</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>0.39</td>
</tr>
</tbody>
</table>

Table 5.4 shows that the statistical results include the outliers in the levee toe lines of Levee system 1, Levee systems 2 and 3 group, and Levee systems 4 and 5 group. To identify the outliers in the generated levee lines, the line graphs of the horizontal and vertical distances from each checkpoint to the levee lines of each levee system group are presented in Figures 5.14. The outliers are shown with the black circles in Figure 5.14.
(a) Line graph 1: Horizontal distance from each checkpoint to the levee top and toe lines of Levee system 1.

(b) Line graph 2: Vertical distance from each checkpoint to the levee top and toe lines of Levee system 1.

(c) Line graph 3: Horizontal distance from each checkpoint to the levee top and toe lines of Levee systems 2 and 3.

Figure 5.14 Line graphs of the horizontal and vertical distance from each checkpoint to the generated levee lines of each levee system group (Continued).
(d) Line graph 4: Vertical distance from each checkpoint to the levee top and toe lines of Levee systems 2 and 3.

(e) Line graph 5: Horizontal distance from each checkpoint to the levee top and toe lines of Levee systems 4 and 5.

(f) Line graph 6: Vertical distance from each checkpoint to the levee top and toe lines of Levee systems 4 and 5.

Figure 5.14 continued
(g) Line graph 7: Horizontal distance from each checkpoint to the levee top and toe lines of Levee systems 6, 7 and 8.

(h) Line graph 8: Vertical distance from each checkpoint to the levee top and toe lines of Levee systems 6, 7 and 8.

(i) Line graph 9: Horizontal and vertical distance from each checkpoint to the levee berm line of Levee system 3.
In Figure 5.14, the levee toe lines of Levee systems 2, 3 and 5 have outliers caused by extremely low slopes on the toe surfaces. As mentioned in Tables 5.2 and 5.3, 95 ~ 100% of the levee toe lines located in all levee systems consists of the plate boundaries extracted from the LiDAR data. Therefore, all outliers found in the levee toe lines occur on the plate boundary segment selected as the levee toe lines. Figure 5.15 shows an example area where the plate boundary segment (red line) of the levee toe lines of Levee system 3 has an outlier (Profile 3, Point index 11 in Figure 5.6).

![Figure 5.15 Example of the outlier (Profile 3, Point index 11 in Figure 5.14) in the plate boundaries of Levee system 3 with corresponding elevation profile: the plate boundary segment (red) and digitized (yellow) line.](image)

In Figure 5.15, the plate boundary segment (red line) selected as the levee toe lines include an outlier. In this dissertation, the breakline detection method is used to generate the plate boundaries from the LiDAR data based on the assumptions that the levee toes generally have sharp edges due to wave actions (USACE, 2006) and the levees are designed to have at least 18.43° on their slope plates (MOLIT, 2009).
However, due to erosion occurring on the levee surfaces, sediment transport during floods, sediments (the object in the green circles) is deposited on the toe surfaces. The elevation profile in Figure 5.15 shows that the toe surfaces where the sediment is located have extremely low slopes compared to the levee slope plates, and the plate boundaries selected as the levee toe lines have the outlier. To refine the statistical results, we remove these outliers in the results shown in Table 5.4. Table 5.5 shows a comparison between the original results and the refined results of the horizontal and vertical accuracies of the generated levee lines.

Table 5.5 Comparison between the original results and the refined results of the horizontal and vertical accuracies of the generated levee lines.

<table>
<thead>
<tr>
<th>Levee</th>
<th>Levee Top</th>
<th>Levee Toe</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Horizontal Distance (m)</td>
<td>Vertical Distance (m)</td>
</tr>
<tr>
<td>Original</td>
<td>Average</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>St. Deviation</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>0.39</td>
</tr>
<tr>
<td>Refined</td>
<td>Average</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>St. Deviation</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>0.39</td>
</tr>
</tbody>
</table>

In Table 5.5, the accuracies of the results of the levee top lines are not refined by removing the outliers because an outlier is not detected in the original results. However, the accuracy results of the levee toe lines are significantly refined by removing the outliers because multiple outliers are detected and removed in the original results.
5.3 Analysis of accuracies of the levee lines using various factors

The horizontal and vertical accuracies of the generated levee lines are analyzed using various factors. As seen in Figures 5.4, 5.5, 5.6, 5.8, 5.9, 5.10, 5.11 and 5.12, and as mentioned in Tables 5.2 and 5.3, each levee system has different objects on its surface, different slope patterns, different types (CL and GL) and different levels of levee failure risks. Each factor is separately considered in order to analyze the accuracies of both levee top and toe lines.

① Analysis of accuracies of the levee lines located on different objects

The levee top and toe lines consist of multiple baselines (the plate boundaries extracted from the LiDAR data, the cluster boundaries extracted from the clusters or the edges extracted from the image sources) in all levee systems. The plate boundaries are extracted in all levee systems, the edges are extracted along the boundaries of the asphalt and gravel roads and the slope blocks, and the cluster boundaries are extracted along the boundary of the soil road. The extracted edges and cluster boundaries are selected using the judgment test and are used as the levee top or toe lines instead of the plate boundaries. Table 5.6 shows the accuracy of the levee lines, generated by using only the plate boundaries and multiple baselines, located on various objects.
Table 5.6 Accuracies of the levee lines, generated by using only the plate boundaries and multiple baselines, located on various objects.

<table>
<thead>
<tr>
<th></th>
<th>Plate boundaries</th>
<th>Multiple baselines</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Horizontal</td>
<td>Vertical</td>
</tr>
<tr>
<td>Accuracies of the levee</td>
<td>difference (m)</td>
<td>difference (m)</td>
</tr>
<tr>
<td>lines located on the asphalt road</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>0.35</td>
<td>0.06</td>
</tr>
<tr>
<td>St. Deviation</td>
<td>0.25</td>
<td>0.04</td>
</tr>
<tr>
<td>Max</td>
<td>1.00</td>
<td>0.18</td>
</tr>
</tbody>
</table>

Accuracies of the levee lines located on the unpaved top road (gravel/soil roads)

<table>
<thead>
<tr>
<th></th>
<th>Plate boundaries</th>
<th>Multiple baselines</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Horizontal</td>
<td>Vertical</td>
</tr>
<tr>
<td>Accuracies of the levee</td>
<td>difference (m)</td>
<td>difference (m)</td>
</tr>
<tr>
<td>lines located on the levee berm (gravel/soil roads)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>0.19</td>
<td>0.06</td>
</tr>
<tr>
<td>St. Deviation</td>
<td>0.26</td>
<td>0.04</td>
</tr>
<tr>
<td>Max</td>
<td>1.40</td>
<td>0.24</td>
</tr>
</tbody>
</table>

Accuracies of the levee toe lines

<table>
<thead>
<tr>
<th></th>
<th>Plate boundaries</th>
<th>Multiple baselines</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Horizontal</td>
<td>Vertical</td>
</tr>
<tr>
<td>Accuracies of the levee</td>
<td>difference (m)</td>
<td>difference (m)</td>
</tr>
<tr>
<td>toe lines</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>0.23</td>
<td>0.08</td>
</tr>
<tr>
<td>St. Deviation</td>
<td>0.75</td>
<td>0.25</td>
</tr>
<tr>
<td>Max</td>
<td>0.73</td>
<td>0.45</td>
</tr>
</tbody>
</table>

Table 5.6 shows that the overall accuracy of the levee lines, generated by using only the plate boundaries, located on paved roads and levee berms are better than the average point density of the LiDAR data, but worse than the pixel resolution of the images. The overall accuracies of these levee lines are improved by using multiple baselines, and are better than the pixel resolution of the images. The overall accuracy of the levee lines, generated by using only the plate boundaries or multiple baselines,
located on the unpaved roads and toe surfaces, are better than the pixel resolution of the images. In Table 5.6, accuracy of the levee lines located on three different objects (asphalt road, unpaved road and levee berm) are improved by using multiple baselines instead of using only the plate boundaries. Figure 5.16 shows example areas having the edge segments (blue lines) or the cluster boundary segments (green lines) selected as the levee top lines, the non-selected plate boundary segments (red lines) and the reference lines (yellow lines).

Figure 5.16 Example areas having the edge segments (blue) or the cluster boundary segments (green) selected as the levee top lines, the non-selected plate boundary segments (red) and the reference line (yellow) (Continued).
Figure 5.16 continued

(b) The edge segment (blue), the plate boundary segment (red) and the reference line (yellow) in Levee system 5.

(c) The cluster boundary segment (green), the plate boundary segment (red) and the reference line (yellow) in Levee system 6.

Figure 5.17 shows an example area having the edge segment (blue line) selected as the levee berm line, the non-selected plate boundary segment (red line) and the reference line (yellow line) in Levee system 3.
Figure 5.17 Example area having the edge segment (blue) selected as the levee berm line, the non-selected plate boundary segment (red) and the reference line (yellow).

Figure 5.18 shows an example area having the edge segment (blue line) selected as the levee toe line, the non-selected plate boundary segment (red line) and the reference line (yellow line) in Levee system 3.

Figure 5.18 Example area having the edge segment (blue) selected as the levee toe line, the non-selected plate boundary segment (red), and the reference line (yellow).

Figures 5.16, 5.17 and 5.18 show that the edge or cluster boundary segments
are useful for describing the levee surfaces having relatively smooth terrains.

(2) Analysis of accuracies of the levee lines by using the slope parameter

The levee line segments on the surfaces having different slope patterns have different accuracies. Among the three baselines, the plate boundaries are generated by using only the geometric parameters and the other baselines (the edges and cluster boundaries) are generated by using the spectral parameters. This section compares the accuracies of the plate boundaries and the other baselines located on the levee surfaces divided by the slope parameter. We divide the types of surfaces into two types using the slope values derived from the slope map generated in Chapter 2: steep terrains and smooth terrains. Based on the construction law made by the MOLIT (2009), surfaces that have slope values higher than 8.43° are defined as steep terrains and surfaces that have slope values lower than 8.43° are defined as smooth terrains. Table 5.7 shows the accuracy of the plate boundaries and other baselines located on different terrains divided by the slope parameter.
Table 5.7 shows that the plate boundaries have higher accuracy than the other baselines on the steep terrains, and the other baselines (the edges and cluster boundaries) have higher accuracies than the plate boundaries on the smooth terrains. As seen Figures 5.16, 5.17 and 5.18, the edge segments or cluster boundary segments selected as the levee lines have higher accuracy than the non-selected plate boundary segments on the surfaces where slopes gradually change. However, the plate boundary segments selected as the levee lines have higher accuracies than the non-selected edge segments or cluster boundary segments on the surfaces where slopes change sharply. Figure 5.19 shows an example area having the plate boundary segment (red line) selected as the levee top line, the non-selected edge segment (blue line) and the reference line (yellow line) in Levee system 6.
Figure 5.19 Example area showing the plate boundary segment (red) selected as the levee top line, the non-selected edge segment (blue) and the reference line (yellow) in Levee system 6.

In Figure 5.19, the edge segment is not selected as the levee top line by using the judgment test because it is located on flat terrains. Due to wave attacks by the water flow and erosion occurring on the toe surfaces, the elevation of the edges is generally higher than the elevation of the plate boundaries on the toe surfaces. Figure 5.20 shows an example area having the plate boundary segment (red line) selected as the levee toe line, the non-selected edge segment (blue line) and the reference line (yellow line) in Levee system 1.
Figure 5.20 Example area having the plate boundary segment (red) selected as the levee toe lines, the non-selected edge segment (blue) and the reference line (yellow) in Levee system 1.

In Figure 5.20, the elevation of the plate boundary segment is lower than the elevation of the edge segment. Hence, the plate boundary segment is selected as the levee toe line segment by the judgment test.

In conclusion, the plate boundary segments selected as the levee lines are generally more suitable than the edge segments or cluster boundary segments for describing the levee surfaces having relatively steep terrains regardless of the major objects on the surfaces.

③ Analysis of accuracies of the levee lines on different levee types

The accuracies of the levee lines on different levee types are also compared. Table 5.8 shows the accuracies of the levee lines on different levee types: typical concrete levees (CL) and typical green levees (GL).
Table 5.8 Accuracies of the levee lines on different levee types.

<table>
<thead>
<tr>
<th></th>
<th>Accuracies of the levee top lines on CL</th>
<th></th>
<th></th>
<th>Accuracies of the levee top lines on GL</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plate boundaries</td>
<td>Multiple baselines</td>
<td></td>
<td>Plate boundaries</td>
<td>Multiple baselines</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Horizontal difference (m)</td>
<td>Vertical difference (m)</td>
<td>Horizontal difference (m)</td>
<td>Vertical difference (m)</td>
<td>Horizontal difference (m)</td>
<td>Vertical difference (m)</td>
</tr>
<tr>
<td>Average</td>
<td>0.34</td>
<td>0.05</td>
<td>0.14</td>
<td>0.04</td>
<td>0.19</td>
<td>0.06</td>
</tr>
<tr>
<td>St. Deviation</td>
<td>0.25</td>
<td>0.03</td>
<td>0.11</td>
<td>0.03</td>
<td>0.26</td>
<td>0.04</td>
</tr>
<tr>
<td>Maximum</td>
<td>0.93</td>
<td>0.13</td>
<td>0.39</td>
<td>0.09</td>
<td>1.40</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Accuracies of the levee toe lines located on both levee types</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CL</td>
<td>GL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Horizontal difference (m)</td>
<td>Vertical difference (m)</td>
<td>Horizontal difference (m)</td>
<td>Vertical difference (m)</td>
<td>Horizontal difference (m)</td>
<td>Vertical difference (m)</td>
</tr>
<tr>
<td>Average</td>
<td>0.13</td>
<td>0.06</td>
<td>0.09</td>
<td>0.05</td>
<td>0.10</td>
<td>0.03</td>
</tr>
<tr>
<td>St. Deviation</td>
<td>0.10</td>
<td>0.03</td>
<td>0.05</td>
<td>0.04</td>
<td>0.37</td>
<td>0.13</td>
</tr>
<tr>
<td>Maximum</td>
<td>0.37</td>
<td>0.13</td>
<td>0.18</td>
<td>0.15</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5.8 shows the refined levee top lines on both levee types have higher accuracies than the levee top lines generated by using only the plate boundaries. As seen in Tables 5.6 and 5.7, the accuracies of the levee top lines, generated by only using the plate boundaries, on the paved or unpaved roads is improved by using multiple baselines. Due to the general characteristics of the toe surfaces, the accuracy of the levee toe lines generated in both levee types is similar regardless of the levee type.

④ Analysis of accuracies of the levee lines located on the areas having erosions

Accuracies of the levee lines located on the areas having the different failure
risks are compared. In Chapter 4, the types of the levee failure risks are divided into the three categories: risk of overtopping, risk of top failure and risk of slope failure. In this section, accuracies of the levee lines located on the areas having safe conditions from levee failures, risk of top failures and risk of slope failures are compared. Table 5.9 shows accuracies of the levee lines located on the areas having safe conditions from levee failures, risk of top failure and risk of slope failure.

Table 5.9 Accuracies of the levee lines located on the areas having safe conditions from levee failures, risk of top failures and risk of slope failures.

<table>
<thead>
<tr>
<th></th>
<th>Accuracies of the levee top lines on the areas having safe conditions from top failure</th>
<th>Accuracies of the levee top lines on the areas having risk of top failure</th>
<th>Accuracies of the levee toe lines on the areas having different level of levee failure risks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plate boundaries</td>
<td>Multiple baselines</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Horizontal difference (m)</td>
<td>Vertical difference (m)</td>
<td>Horizontal difference (m)</td>
</tr>
<tr>
<td>Average</td>
<td>0.34</td>
<td>0.05</td>
<td>0.14</td>
</tr>
<tr>
<td>St. Deviation</td>
<td>0.25</td>
<td>0.03</td>
<td>0.11</td>
</tr>
<tr>
<td>Maximum</td>
<td>0.93</td>
<td>0.13</td>
<td>0.39</td>
</tr>
</tbody>
</table>

In the levee information systems established in the study area, the top plates
having safe conditions from top failures have paved roads, while the top plates having the risk of top failures have unpaved roads. Hence, the levee top lines located on the areas having safe conditions from levee failures, the risk of top failures are refined by using multiple baselines as mentioned in the above paragraphs. Due to the general characteristics of the toe surfaces, both levee toe lines located on the areas having the safe conditions or the risks of slope failure have similar accuracies regardless of the risk level of levee failures.

Based on analysis using various factors, we obtain multiple conclusions illustrated in the following paragraphs.

1. The accuracies of the levee lines located on paved roads, unpaved roads and berms are significantly improved by using multiple baselines, while the accuracies of the levee lines located on the toe surfaces are slightly improved by using multiple baselines.

2. The edge segments or the cluster boundary segments selected as the levee lines are the more useful sources than the plate boundary segments to describe the levee surfaces having smooth terrains, while the plate boundary segments selected as the levee lines are the more useful sources than the edge segments or cluster boundary segments to describe the levee surfaces having steep terrains.

3. The edge segments or the cluster boundary segments are generally useful for describing the boundaries of major objects located near the upslope or downslope terrains, while the plate boundary segments are generally useful for describing the boundaries of the top or slope plates having steep terrains.
regardless of the major objects on their surfaces.

4. Due to wave attacks by the water flow, erosion occurring on the toe surfaces and shadows located on the toe surfaces, the edge segments are rarely selected as the levee lines by the judgment test.

5. The plate boundary segments selected as the levee toe lines have the outliers on the toe surfaces having extremely low slopes caused by levee depositions and having only the plate boundary segments available.

5.4 Comparison of the results with the historical research

This section compares the accuracies of the levee lines generated in this research and the accuracies of the levee lines generated by historical researchers. Historically, research on mapping of the levee/dike lines by using the LiDAR data has been carried out by Brügelmann (2000) from The Netherlands survey department and Brzank et al. (2008) from the University of Hannover, Germany. Brügelmann (2000) extracted the dike lines from the LiDAR DEM by using the edge detection method, and Brzank et al. (2008) extracted the structure lines, including the dike lines in coastal areas, from the LiDAR DEM by using the hyperbolic tangent function. Table 5.10 shows comparison of the accuracies of the levee lines generated by historical research and this research.
Table 5.10 Comparison of the accuracies of the levee lines generated by historical research and this research.

<table>
<thead>
<tr>
<th>Accuracies of the levee/dike lines generated by historical research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brügelmann (2000) from The Netherlands survey department, The Netherlands</td>
</tr>
<tr>
<td>Brzank et al. (2008) from the University of Hannover, Germany</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Accuracies of the levee lines generated by this research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Levee top lines located on the asphalt road</td>
</tr>
<tr>
<td>Original</td>
</tr>
<tr>
<td>Horizontal difference (m)</td>
</tr>
<tr>
<td>0.35</td>
</tr>
<tr>
<td>Levee top lines located on the unpaved road</td>
</tr>
<tr>
<td>Original</td>
</tr>
<tr>
<td>Horizontal difference (m)</td>
</tr>
<tr>
<td>0.19</td>
</tr>
<tr>
<td>Levee toe lines</td>
</tr>
<tr>
<td>Original</td>
</tr>
<tr>
<td>Horizontal difference (m)</td>
</tr>
<tr>
<td>0.12</td>
</tr>
</tbody>
</table>

In the historical research, the geometric parameters are only used to extract levee/dike lines from the LiDAR digital elevation models (DEM). In this research, multiple parameters are used to extract the levee lines located on various levee surfaces. Considering the general design patterns of the levees in South Korea and the general characteristics of the materials on the levee surfaces, the three baselines (the edges extracted from the image sources, the cluster boundaries extracted from the clusters and the plate boundaries extracted from the LiDAR data) are used separately.
as the levee lines on the various levee surfaces. Since the LiDAR data provides only the geometric parameters, the levee lines generated by using only the LiDAR data are limited to describe the various levee surfaces. This research contributes to generating levee lines that are suitable for describing various levee surfaces by using multiple baselines.

5.5 Failure risk assessment of the levee systems in the entire study area

Levee information systems are established in the eight levee systems in the entire study area by using the methods introduced in Chapter 4. This section assesses the failure risks of the levee systems in the entire study area by using the established levee information systems. Figure 5.21 shows the levee information systems in the study area. In Figure 5.21, Changnyeong City is protected by Levee systems 1, 2, 3 and 4, and Milyang City is protected by Levee system 5, and Changwon City is protected by Levee systems 6, 7 and 8. As mentioned in Chapter 4, the green lines show a safe condition from levee failure, the blue lines show a low level risk of levee failure, the yellow lines show a middle level risk of levee failure, and the red lines show a high level risk of levee failure.
Figure 5.21 Levee information systems established in the entire study area.

Changnyeong City is protected by Levee systems 1, 2, 3 and 4. Figure 5.23 shows Levee information systems 1, 2, 3 and 4 located in Levee systems 1, 2, 3 and 4.

(a) Levee information system 1 (Risk level: safe (green lines)).

Figure 5.22 Levee information systems 1, 2, 3 and 4 protecting Changnyeong City (Continued).
Figure 5.22 continued

(b) Levee information system 2 (Risk level: low level (blue lines)) and Levee information system 3 (Risk level: safe (green lines) and low level (blue lines)).

(c) Levee information system 4 (Risk level: middle level (yellow lines)).

In Figure 5.22, the typical CLs (Levee system 1 and the first levee of Levee system 3) that consist of the asphalt road on their top plates and concrete blocks on their riverside slope plates have a safe condition from levee failure. These levees have the appropriate top plate widths that are higher than the minimum widths of the top plates (7 m) and the appropriate heights that are higher than the minimum heights of the top plates (Levee system 1: 15.43 m, Levee system 3: 14.65 m). However, Levee system 2, that consists of the asphalt road on its top plate and natural blocks on its slope plates, has a low level risk of levee failures caused by their heights being lower...
than the minimum height of the top plate (Levee system 2: 14.98 m). In addition, the second levee of Levee system 3 that consists of a gravel road on its top plate and concrete blocks on its riverside slope plate also has a low level risk of levee failure caused by their top widths being shorter than the minimum widths of the top plate (7 m). Levee system 4, the typical GL, has a middle level risk of levee failure caused by their heights being lower than the minimum height of the top plate (Levee system 4: 14.34 m) and top widths being shorter than the minimum widths of the top plate (7 m).

Figure 5.23 shows Levee information system 5 established in Levee systems 5 protecting Milyang City, and Figure 5.24 shows Levee information systems 6, 7 and 8 located in Levee system 6, 7 and 8 protecting Changwon City.

![Figure 5.23 Levee information system 5 (Risk level: middle level (yellow lines)) protecting Milyang City.](image)
In Figures 5.23 and 5.24, the typical GLs, that consist of gravel/soil roads on their top plates and natural blocks on their slope plates, have a middle level risk of levee failures caused by their heights being lower than the minimum heights of the top plates (Levee system 5: 13.49 m, Levee systems 6, 7 and 8: 13.54 m) and their top widths are shorter than the minimum widths of the top plate (7 m). Additionally, some areas on the GLs having the risk of slope failure are evaluated to have a high level risk of levee failure. Table 5.11 shows the summarized assessment of the failure risks of the levee systems in the study area.
Table 5.11 Summarized assessment of the failure risks of the levee systems in the study area.

<table>
<thead>
<tr>
<th>City Name</th>
<th>Levee system</th>
<th>Risk level of levee failures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changnyeong</td>
<td>Levee system 1 (CL)</td>
<td>Safe</td>
</tr>
<tr>
<td></td>
<td>Levee system 2 (partial CL)</td>
<td>Low level risk (Major reason: risk of overtopping)</td>
</tr>
</tbody>
</table>
|             | Levee system 3 (first: CL and second: partial CL) | CL: Safe  
Partial CL: Low level risk (Major reason: risk of top failure)                         |
|             | Levee system 4 (GL)               | Middle level risk (Major reasons: risks of overtopping and top failure)                      |
| Milyang     | Levee system 5 (GL)               | Middle level risk (Major reasons: risks of overtopping and top failure)                      |
| Changwon    | Levee system 6 (GL)               | Middle and high level risks (Major reasons: risks of overtopping, top failure and slope failure) |
|             | Levee system 7 (GL)               | Middle and high level risks (Major reasons: risks of overtopping, top failure and slope failure) |
|             | Levee system 8 (GL)               | Middle level risk (Major reasons: risks of overtopping and top failure)                      |

Table 5.11 shows that the typical CLs protecting Changnyeong City generally have safe conditions from levee failure, while the partial CLs protecting Changnyeong City generally have low level risks of levee failure caused by the risk of top failure or overtopping. However, the GLs protecting Changwon City and Milyang City generally have middle and high level risks of levee failure caused by the risk of overtopping and top failure. In conclusion, the typical CLs generally have safe conditions from levee failure, the partial CLs, whose surfaces are partially covered by paved surfaces, have low level risk of levee failure, and the typical GLs have middle or high level risks of levee failure. In the entire study area, the areas of Changwon
City protected by the CLs are the safest from flooding, while other areas are exposed to flooding risks due to the levees with levee failure risks.

5.6 Summary

This chapter shows the accuracies of the levee lines generated by using three baselines (the plate boundaries extracted from the LiDAR data, the edges extracted from the images and the cluster boundaries extracted from the clusters) and analyzes the accuracies of the generated levee lines located on various levee surfaces using various factors. The plate boundaries are extracted in all levee systems, while the edges and cluster boundaries are partially extracted based on major objects on the levee surfaces. Overall, the results show that the accuracies of the levee lines generated using only plate boundaries are improved by using multiple baselines. Assessment of the failure risks of the levee systems in the study area (Changnyeong, Changwon and Milyang Cities) is also performed in this chapter. The results of the risk assessment show that the areas protected by the CLs are the safest from flooding due to the levees having safe conditions from failure, while the other areas are exposed to flood risks due to the levees having failure risks.
CHAPTER 6: CONCLUSIONS AND FUTURE RESEARCH

This dissertation discusses mapping levees for river basin management using airborne topographic LiDAR data and multispectral aerial orthoimages. This dissertation includes multiple contributions for mapping levees as illustrated in the following paragraphs.

1) This dissertation suggests new methods for identifying various features, such as major objects and eroded areas on the levee surfaces, by using geometric and spectral information provided by LiDAR data and multispectral orthoimages. First, slope difference analysis and elevation and area analysis are used to identify the levee top, slope, berm, plates and eroded areas having different geometric patterns. Next, clustering algorithms are applied to identify the major objects on each levee plate. Finally, the major objects (asphalt, gravel or soil roads, concrete or natural blocks) having different geometric and spectral characteristics and the eroded area are identified on various levee surfaces using the entire procedure.
Overall, the identified objects on the concrete levees have 90% accuracy by using K-means clustering, and the identified objects on the green levees have 86% accuracy by using ISODATA clustering. This dissertation contributes to identifying multiple components, including the major objects and eroded areas having different geometric and spectral patterns.

2) This dissertation introduces new methods for mapping levee lines by using multiple baselines (edges extracted from the images, cluster boundaries extracted from the identified clusters and the plate boundaries extracted from the LiDAR data). First, the three baselines are extracted separately from different sources. The judgment test is then performed to select one baseline as the levee line segment on each segment. Finally, the levee lines consisting of multiple baselines are generated on various levee surfaces. Overall, the accuracy of the levee top, toe and berm lines consisting of multiple baselines are better than the pixel resolution of the given images. And the levee lines consisting of multiple baselines have better accuracy ((top of the paved road) horizontal: 20cm, vertical: 2cm; (top of the unpaved road) horizontal: 10cm, vertical: 1cm; (berm) horizontal: 24cm, vertical: 2cm; (toe) horizontal: 1cm) than the levee lines generated using only the plate boundaries. This dissertation contributes to identifying the most suitable levee lines on various levee surfaces having the different geometric and spectral patterns.

3) This dissertation introduces methods for assessing the failure risks of the levee systems in the Nakdong River basins by using the generated levee lines and identified objects on levee surfaces. First, the various risks causing levee
failure are separately evaluated on each levee segment. Second, the level of levee failure risks on each segment is measured using the identified risks for each levee segment. Third, the levee segments with failure risks are shown along the levee lines with specific colors (red, blue, yellow and green). Finally, the levee information systems showing failure risks for levee systems in the study area are established. Using the established information systems, this dissertation contributes to identifying the areas in the Nakdong River basins that are exposed to flood risks.

In summary, the multiple technical improvements developed in this dissertation are illustrated as follows.

1) The multiple geometric analysis approaches, such as slope difference analysis and elevation and area analysis, are developed to identify the top, slope, berm plates and the eroded areas having different geometric patterns on levee surfaces.

2) The judgment test is developed to select the levee line segments on various levee surfaces. The judgment test is carried out using the geometric patterns of the areas where the baselines are located. Using the judgment test, a single baseline is selected as the levee line segment on the levee surface.

3) The method for establishing the levee information system is developed by using the generated levee lines and identified features on levee surfaces. This method consists of multiple sub-methods in order to measure multiple levee failure risk types (risk of overtopping, slope failure and top failure) on each levee segment by using different parameters.
The work to be performed in the future is described in the following paragraphs.

1) For future levee mapping tasks, images having broad spectral bands, such as the hyperspectral images, are required. Because of erosion or wave actions occurring on the levee surfaces, edges or cluster boundaries are not well extracted on some surfaces where the levee objects boundaries are not recognized in multispectral images or LiDAR DSM. Also, using only multispectral images limits identifying various surface conditions such as soil moisture or vegetation types on the levee surfaces. Hence, future research is necessary to improve the tasks for mapping levee surfaces and lines using images having broad spectral bands.

2) A combination of the results derived from the remote sensing data sets with flood modeling is necessary to improve tasks for mapping the levees. In general, the topographic changes occurring on the levee surfaces are caused by levee depositions or a cut on the toe surfaces by wave actions. Mapping some levee areas is limited by using only remote sensing data sets due to those activities. Using flood modeling is efficient for estimating the topographic changes on levee surfaces (Flor et al., 2010; Zinke et al., 2011). Hence, future research is needed for the improved tasks of mapping levees by combining the results derived from remote sensing data sets with flood modeling.
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